UWB Radio Wireless Communication System Design for Railway Tunnels

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UWB Radio Wireless Communication System Design For Railway Tunnels

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By

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<u>CERTIFICATE</u>

This is to certify that the thesis entitled **"Ultra Wideband Radio Wireless Communication System Design for Railway Tunnels"** submitted by **Mr. Medhavi Mahobe**, in partial fulfillment of the requirements for the award of Master of Technology (Regular) in Electrical Engineering, with specialization of **'Electronic Systems and Communication'** at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter presented in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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ABSTRACT

Railway is an economical and comfortable mode of transportation for long distances. Huge population from all over the world depends on it for their daily routine. Railway mainly transports passengers and goods from one place to another. Safety, reliability and good quality of service are the main concern of railway industries which are maintained by railway management and communication system. There are several existing management systems like CCCS, ATCS, PTC and many more. With increasing population, demand for railway services also increases. To full fill these demands railway infrastructure has been developing continuously. By implementing latest technologies for railway communication we can make railway transportation safer, efficient, and more accessible. Ultra wideband radio communication system is amongst those very latest and rapidly growing technologies. This research work focuses on the study of UWB radio based wireless communication system for railway tunnels, whose main task is to maintain an uninterrupted data transmission between train driver to wayside controller. UWB technology is defined as a transmission system which has a fractional bandwidth of more than 20% or an absolute bandwidth of more than 500 MHz in the frequency range of 3.1 GHz to 10.6 GHz. This much larger bandwidth allows a very high data rate up to maximum 480 Mbps, which is beneficial in case of emergency in railway networks. We have studied the rectangular shaped railway tunnel environment as wireless channel by considering ray theory model of wave propagation. We evaluated the frequency response, channel impulse response and path loss for different distances between transmitter and receiver and observed the effect of fading over the channel. Then three standard wave shapes has been tested with the modelled channel. It is to observe the phase shift and time delay provided by the considered channel model which behaves as a multipath fading channel with additive white Gaussian noise. To check the quality of reception bit error rate performance has been evaluated for BPSK and OOK modulation techniques. All the channel characteristics show that UWB systems perform better than the existing techniques. So to maintain the continuity of data stream we need to install UWB trans-receiver over the specific interval, in our study it is 15 to 25 meter. Since UWB is based on carrier less transmission so UWB equipment are less complex than carrier based transmission, so we can settle for short range with extremely high data rate communication.

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LIST OF ABBREVIATIONS

Abbreviations	Description
ATCS	Advanced Train Control Systems
ATP	Automatic Train Protection
ATO	Automatic Train Operation
ATS	Automatic Train Supervision
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CBTC	Communications-Based Train Control Systems
CCCS	Command Control and Communications Systems
EPLRS	Enhanced position and location reporting system
ETCS	European Train Control System
FCC	Federal Communications Commission
GSM-R	Global System for Mobile communications version for the rail industry
ITCS	Incremental Train Control Systems
LOS	Line of Sight
MGF	Modified Gegenbauer Functions
NLOS	Non Line of Sight
OOK	On-Off Keying
PSD	Power Spectral Density
PTC	Positive Train Control
PTS	Positive Train Separation
S–V	Saleh and Valenzuela model
TETRA	Terrestrially Trunked Radio
UWB	Ultra Wide-Band

Chapter 1

INTRODUCTION

Chapter 1

INTRODUCTION

1.1 INTRODUCTION

Wireless communication system has become integral part of modern transportation system. Advancement in communication technology makes the human effort very less to analyse and avoid the problems associated in data transmission. We know that communication system mainly divided into two branches based on the channel namely wired communication and wireless communication. In wired communication data exchange takes over some physical cables like optical fiber cable, coaxial cables etc. which of-course is a fast mode of transmission but have some limitations like installation problem, cost of installation and safety concern. While the advancement in wireless communication system enables it to apply in almost all sectors for the exchange of information and data.

Railway transportation is one of the areas of interest where the benefits of wireless communication technology can be applied for the betterment of railway industries. Wireless communication assists the vehicular monitoring system by reducing the maintenance and inspection needs of railway transportation along with safety and reliability. Operational railway communication network can be classified into three groups as locomotive, wayside and train control network. Railway transportation maintained by railway management and communication system. Communication based train control system, advanced train control system, positive train control are some of the existing signalling systems which use the wireless communication system. These are mainly used in developed countries, where railway transportation usually operates under tunnel. The existing narrowband wireless communication system do not have the capability to sustain the heavy attenuation provided by tunnel environment, as it has limited bandwidth so optimal receiver designing become bit difficult.

This problem can be avoided by replacing narrow band communication with a wideband communication technology. Ultra wideband is the latest and rapidly growing technology with extremely large band width. Low power spectral density of UWB signals makes it to coexist with other narrowband and wideband signal without any interruptions. Ultra wideband technology has the capability to provide simultaneous ground to train communication, train location and to prevent from possible hazards due to collisions. UWB provides a challenging, economically sensible, as well as technically effective alternative solution to existing signalling technologies used in railway communication systems.

The thesis consist the research work done to design an Ultra wideband radio based wireless communication system inside railway tunnel. Tunnel environment is assumed as multipath fading channel with added white Gaussian noise. Based on this channel model detail analysis has been done to study the effect of path loss and fading over the channel characteristics. Channel also evaluated on the basis of bit error rate performance with increasing distance between transmitter and receiver. Channel responses shows that UWB performs well for short range of about 15 to 25 meter. As distance increases, frequency and path dependent attenuation becomes dominant. This degraded the performance of channel.

This chapter starts with the motivation behind the research work undertaken, followed by objectives of thesis in section 1.3, literature survey in section 1.4 and thesis organization in section 1.5.

1.2 MOTIVATION OF WORK

Short range wireless communication with high speed is the demand of modern urbanized railway transportation system. Urban railways are mainly operates under tunnels. Inside tunnels wave propagation faces the problem of multipath fading, frequency and distance dependent attenuation. Existing narrowband communication system can not withstand these attenuations. It motivates us to use a latest wireless technology called as Ultra wideband communication to overcome the problem of heavy multipath attenuation. UWB has a large bandwidth of the order of 500 MHz and very high data rate beyond 480 Mbps. This makes it a prominent technology to avoid the problem of multipath fading and other distance dependent losses. Further the high data rate allows video data streaming which is help full to develop driver less subway systems.

1.3 OBJECTIVES OF THESIS

Project is to design a UWB radio based wireless communication system for railway tunnel, so the thesis objectives are:

1. To design a wireless channel model for railway tunnel and to study the effect of multipath fading and distance dependent path loss over the channel frequency response and channel impulse response.
2. Three standard UWB pulse shapes (Gaussian pulse, Gaussian mono-pulse and truncated sinusoidal pulse) propagated through modelled channel, to calculate the phase delay and time delay provided by the channel.
3. To evaluate the bit error rate performance by considering BPSK and OOK modulation technique over the channel with increasing distance between transmitter and receiver.

1.4 LITERATURE SURVEY

The railway, with metal wheels running over metallic track invented around 250 years back, proved to be most efficient land transportation which could carry numerous passengers and heavy loads over longer distance. Signalling and communication system used to control the speed of train, to avoid possible hazards and punctual operation of the trains. Trains run over the track on the basis of some rules and guidance, which are must for safety. The most important rule is that two trains should never occupy the same position over the track simultaneously. To ensure that it will not happening, operators and controllers uses signalling and data communication [22] and [12]. With the developing technologies railway signalling and communication systems also developed over the past year as the manual signalling and wired communication replaced by the automatic signalling and wireless communication systems. Latest techniques of data exchange enable to apply the wireless communication for train monitoring which improves the safety and reliability by reducing maintenance and inspection requirements [9]. Several communication and signalling systems are available some of them are communications-based train control (CBTC) systems, advanced train control systems (ATCS), command, control and communications systems (CCCS). Incremental train control systems (ITCS), positive train control (PTC) and positive train separation (PTS) [9]. There are certain aspects of communication and signalling technologies, that it should provide uninterrupted communication between drivers and signallers at any time, any point of the station. It should avail the timely and accurate information about train running status to the passengers and minimum signalling faults [9].

Rail safety management system ensures safe and reliable operation of train. It maintains the traffic in such a way that it limits the risk of injury to persons or damage to property. Track monitoring systems, health card system, autonomous integrated circuit card ticketing system are some of the practically implemented wireless communication technologies which provides safe and secure train operation[9].

Ultra wideband radio communication is amongst the latest wireless technology, which has become a prominent tool since last decade. Though it commercialized in 2002 according to regulations of FCC but it is all started 50 years back [11]. UWB defined as wireless technology which has an absolute bandwidth of the order of 500 MHz within the frequency range of 3.1 GHz to 10.6 GHz. It has a fractional bandwidth of more than 20% at -10 dB emission level. UWB has power spectral density of -41.3 dBm/MHz. So UWB exist with other existing communication system without any interference [29].

UWB with large bandwidth and high data rate capability can provide unique solutions for railway transportation system. It combines the megabit wireless network with the high resolution radiolocation capability. By using UWB, hop by hop data transmission network can be established along the railway track. Such wireless network can provides the precise information about the location and velocity of train [4]. UWB offers simultaneous ground to train communication and obstacle detection. Since the modern railways are mainly operated under tunnel so to understand the problems associated with such environment deterministic channel model and their characteristics has been studied [8]. UWB channel inside railway tunnel faces the problem of multipath fading and distance dependent path loss. Channel frequency response and channel impulse response shows the effect of fading along with distance [3] and [8]. Various UWB pulse shapes and modulation techniques studied to improve the quality of reception [3].

Project work based on the UWB propagation inside railway tunnel. UWB signals reflected from the surfaces of tunnel so tunnel will behave as multipath channel. To understand the propagation we have considered the ray theory model [1]. Railway tunnel is considered as a waveguide which has a cut off frequency of the order of tens of MHz [2].

UWB channel is an important part of complete communication system design. It is must to understand the distortion in each and every multipath component and to measure channel parameters. Multipath propagation and large scale fading effect has been studied to get clear understanding about wave propagation over modelled channel [10].

UWB wireless communication receiving special attention in other industries also like health care, for human motion tracking in athletics etc. It is becoming a leading technology for transmission of audio, video and other high bandwidth data.

1.5 THESIS ORGANIZATION

Thesis consist of total six chapters organized in following order

Chapter 1: Introduction

Chapter 1 consist of objectives, motivation behind the research work and literature survey. This chapter gives brief idea about the railway transportation and its management and communication systems, about the Ultra wideband technology and its possible application in railway industries. It also briefs the problem associated with channel model inside railway tunnel.

Chapter 2: Ultra Wideband Communication System-An Overview

This chapter gives the detailed explanations of Ultra wideband radio technology along with history, definition, advantages and disadvantages of the UWB based communication systems. Various standard UWB pulse shapes have been explained. It also consists of applications of UWB system.

Chapter 3: Wireless Communication Systems for Railway Transportation

This chapter tells about the requirements of an efficient railway management and controlling systems. It gives details about the existing communication and signalling systems for railway control.

Chapter 4: UWB Communication System for Railway Tunnel

This chapter discuss about the protection issues associated with the railway management and controlling system and how the past controlling systems can be replaced by new wireless systems. It elaborates the Ultra wideband channel characteristics i.e. multipath fading effect and large scale fading effect and explained the ray theory model of propagation for railway tunnel as channel. A general UWB communication system model is described along with the different UWB modulation schemes.

Chapter 5: Simulations, Study & Results

Simulations performed by using MATLAB to study the characteristics of designed communication system model under tunnel environment. This section consists of results which show the effect of distance over the channel performance.

Chapter 6: Conclusion and Scope of Future Work

This summarizes and concludes the complete research work. This chapter also consists of possibilities of advancement in research work.

Chapter 2

Ultra Wide-Band Communication System- An Overview

Chapter 2

Ultra Wide-Band Communication System- An Overview

2.1 INTRODUCTION

Ultra wideband wireless communication is an emerging technology with large band width and capability of transmitting data at high rate. It uses low power radio signal, spread over a large frequency spectrum [6] and [29]. It is based on short duration impulses which make it immune for heavy multipath environment. UWB propagation is carrier-less and uses very short pulses for transmission of data [19]. This chapter presents an overview about UWB communication along with history, definition, advantage and disadvantages. Section 2.2 explained various UWB waveforms as pulse shaping is an important problem for designing an UWB based communication system [3]. Section 2.3 contains several applications of UWB in various fields.

2.1.1 OVERVIEW

Ultra-wideband (UWB) transmission has recently received significant attention in both academia and industry for applications in wireless communication. UWB has many benefits, including high data rate, availability of low-cost transceivers, low transmit power and low interference. The approval of UWB technology made by the Federal Communication Commission (FCC) of the United States in 2002 reserves the unlicensed frequency band between 3.1 – 10.6 GHz (7.5 GHz), for UWB wireless communication system. The application of UWB to low cost, low power sensors has a promise. The centimetre accuracy in ranging and communication provides unique solutions to applications, including logistic, security application, medical application, in vehicular technology and military applications [28].

2.1.2 HISTORY

UWB has actually experienced well over 40 years of technological developments. UWB actually had its origins in the spark-gap transmission design of Marconi and Hertz in the late 1890s [11]. So it can say that the first wireless communication system was based on

UWB. But due to technical limitations, narrowband communication was preferred to UWB. Much like the spread spectrum or the code division multiple access (CDMA), UWB followed a similar path with early system designed for military covert radar and communication. The interest in UWB was 'sparked' since the FCC issued a Report and Order allowing its commercial deployment with a given spectral-mask requirement for both indoor and outdoor applications.

2.1.3 DEFINITION

UWB technology is defined by the FCC as any wireless scheme that occupies a fractional bandwidth $\frac{W}{f_c} \geq 20\%$, where W is the transmission bandwidth and *fc* is the band centre, or more than 500 MHz of absolute bandwidth. The FCC approved the deployment of UWB on an unlicensed basis in the 3.1-10.6 GHz band subject to a modified version of part 15.209 rules. The essence of the rulings is that power spectral density (PSD) of the modulated UWB signal must satisfy the spectral masks specified by spectrum regulating agencies and its should be less than -41.3 dBm/MHz, which is less than other wireless communication device. The spectral mask for indoor and outdoor applications specified by FCC in the United States is shown in figure 2.1. Fractional bandwidth can be mathematically described as:

$$B_{fract} = 2\left(\frac{f_h - f_l}{f_h + f_l}\right)$$

(2.1)

2.1.4 ADVANTAGES AND DISADVANTAGES OF UWB SYSTEM

The key benefits of UWB system are [27]:

1. ***High data rates:*** According to Shannon's communication theory, UWB communication system has the capability to achieve high-speed data rate. The information capacity is directly proportional to the bandwidth hence it increases linearly with frequency bandwidth, and decreases logarithmically with the signal to noise ratio. Shannon's equation is as follows:

$$C = B\log_2\left(1+\frac{S}{N}\right) \tag{2.2}$$

Where,

C = maximum channel capacity [bits/second]

B = channel bandwidth [Hz]

S = signal power [watts]

N = noise power [watts]

High data rates enable new applications and devices that would not have been possible up until now.

2. ***Low equipment cost:*** UWB transmission is carrier less, so it has the ability to directly modulate a pulse onto an antenna and hence manufacturers can eliminate many of the components required for conventional sinusoidal transmitters and receivers, which leads the possibilities to design extremely cheap transceivers for UWB system.
3. ***Multipath immunity:*** UWB system uses the narrow pulses, which gives the extremely wide bandwidth, can be separated out with a fine resolution of reflected pulses at the receiver. This is very important in any wireless communication, as pulses are interfering with each other are the major obstacle to error-free communication.
4. ***Ranging and communication simultaneously***: UWB provides both accurate ranging (object location) and high speed data communication in the same wireless device. This characteristic is very useful for vehicular technology as simultaneous automotive collision avoidance radar and communication can give accident free smooth traffic flow.
5. ***Low probability of interception:*** UWB has low probability of detection and Interception, because UWB spectrum spread over a low energy density which makes UWB signal noise like and unintended detection becomes quite difficult. Hence UWB provides high secure and high reliable communication solutions.

With above discussed exciting advantages UWB system becomes a useful technology for future wireless communications and many other applications, but it has some limitations which must be overcome so that it could become a popular and easily accessible technology, some of the challenges are:

1. Since UWB occupies such a wide bandwidth, there are many users whose spectrum will be affected and need to be convinced that UWB will not cause undue interference to their existing services.
2. At present there is no common UWB standards adopted by the industries.
3. Added complexity to avoid interference and low power operation may increase the cost of the UWB devices.
4. UWB uses very short duration pulses of the order of picoseconds precision so the time for a transmitter and receiver to achieve bit synchronization can be as high as a few milliseconds. So channel acquisition time is very high, which significantly affect the performance.

2.2 UWB PULSE SHAPES

UWB systems employ non sinusoidal wave shapes that should have certain properties when transmitted from antenna. Emission in UWB communication systems are constrained by the FCC regulation, which states that 'intentional radiators that produce class B emission (damped wave) are prohibited.

Several non-damped waveforms are available for UWB systems, There are usually referred as Gaussian pulse, Gaussian monocycle (Gaussian pulse of first derivative), Gaussian doublet (Gaussian pulse of second derivative) and Orthogonal polynomial based pulses like Modified Gegenbauer Functions (MGF) [3]. Such waveforms spread the energy over a large bandwidth as they have sharp rise and fall. In addition, the power spectral density is so low for any given frequency that it provides the possibility of low probability of detection or intercepts communications. The short pulses also offer immunity to multipath fading and a much lower fading margin, which gives multipath resolution.

2.2.1 Gaussian Pulse

The zero mean Gaussian pulse is represented by the following equation.

$$x(t) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(\frac{-t^2}{2\sigma^2}\right) \tag{2.3}$$

In equation, σ is standard deviation which also works as time decay constant that determines the impulse duration, and t is the time.

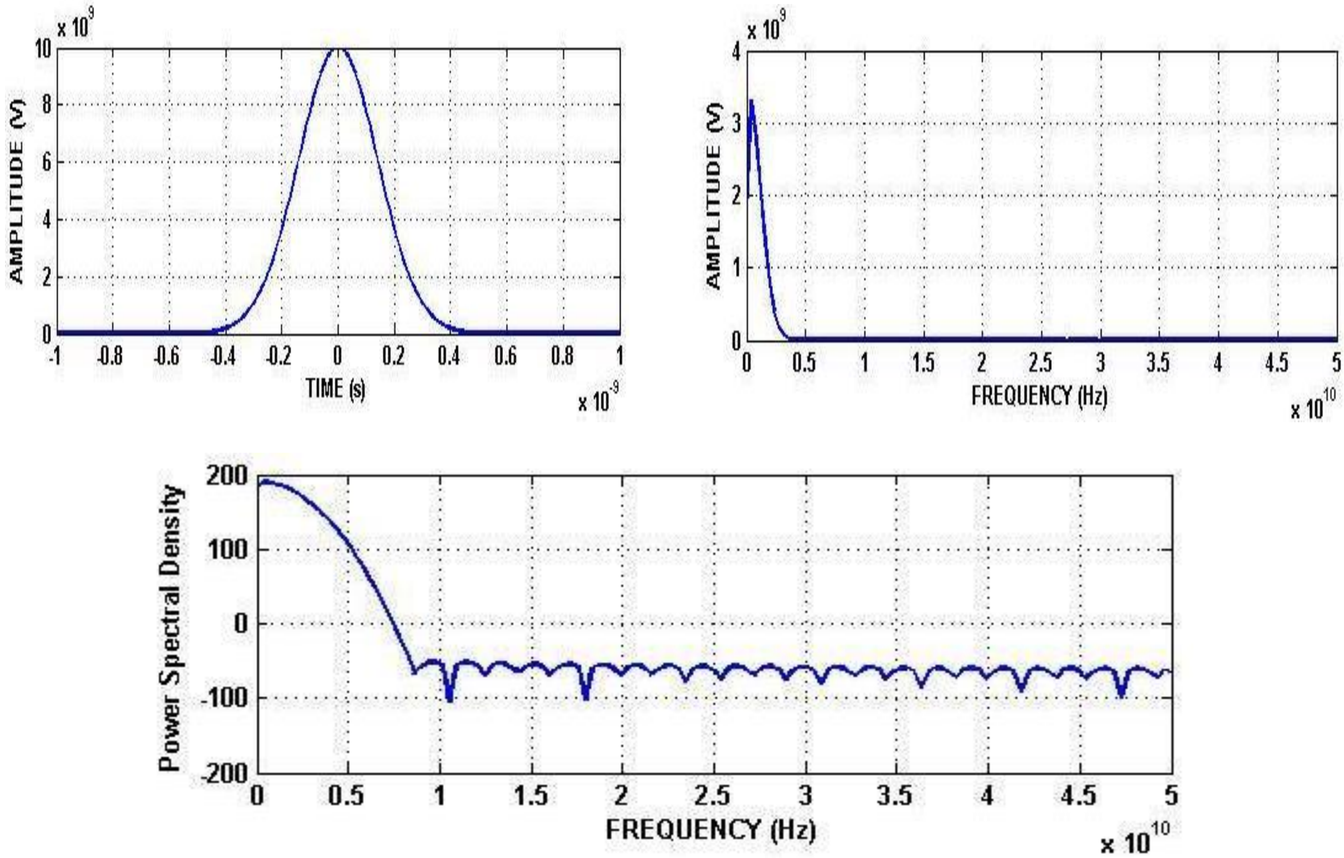


Figure 2.1: Gaussian pulse in time, frequency domain and power spectral density

2.2.2 Gaussian Mono-cycle

The Gaussian monocycle pulse is described as:

$$x'(t) = -\frac{t}{\sqrt{2\pi}\sigma^3}\exp(-\tfrac{t^2}{2\sigma^2}) \tag{2.4}$$

This waveform is mathematically similar to the first derivative of the Gaussian function.

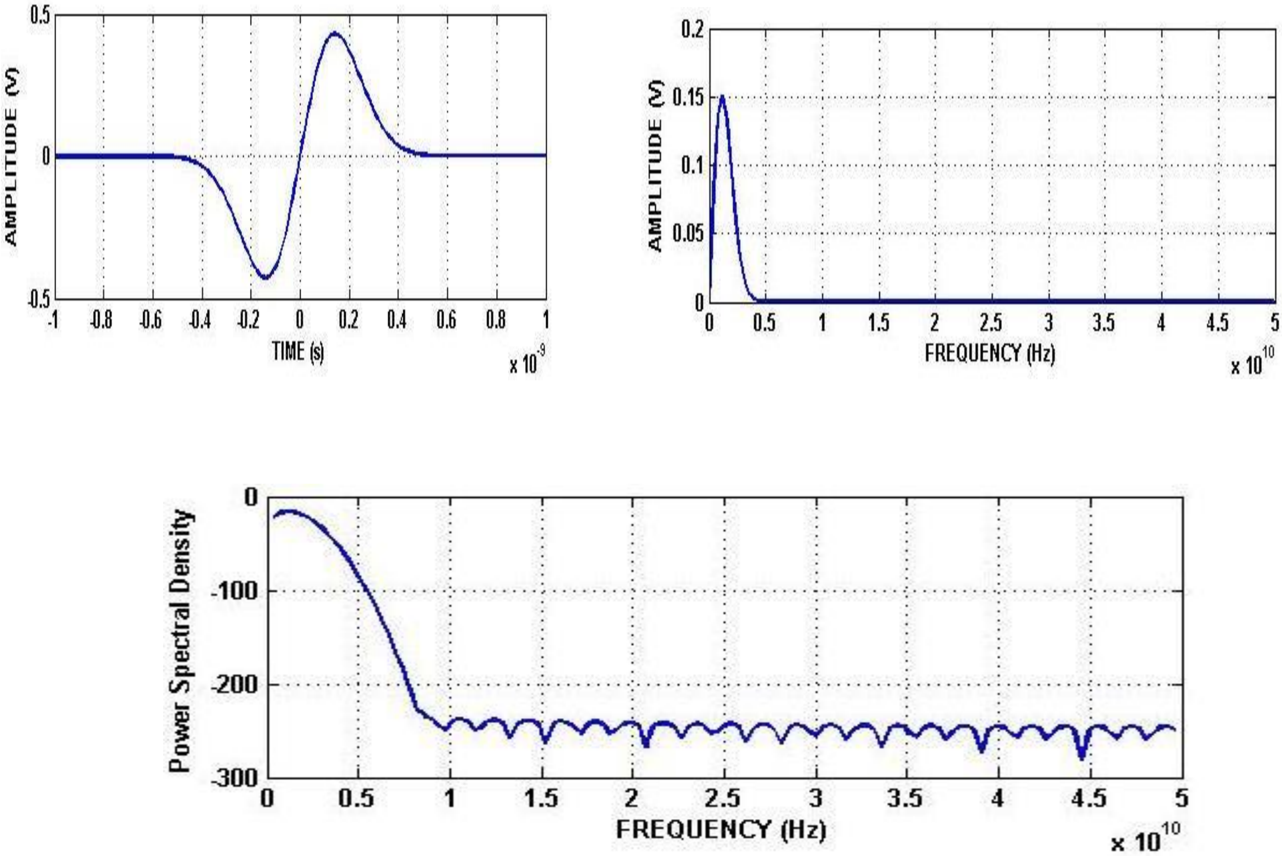


Figure 2.2: Gaussian Mono-cycle in time, frequency domain and power spectral density

2.2.3 Gaussian Doublet

One of the simplest UWB waveforms also to be considered is the Gaussian mono pulse or Gaussian doublet. This represents the second derivative of the Gaussian pulse. Its waveform is given by the equation:

$$x''(t) = -\frac{1-\frac{t^2}{\sigma^2}}{\sqrt{2\pi}\sigma^3}\exp\left(\frac{-t^2}{2\sigma^2}\right) \tag{2.5}$$

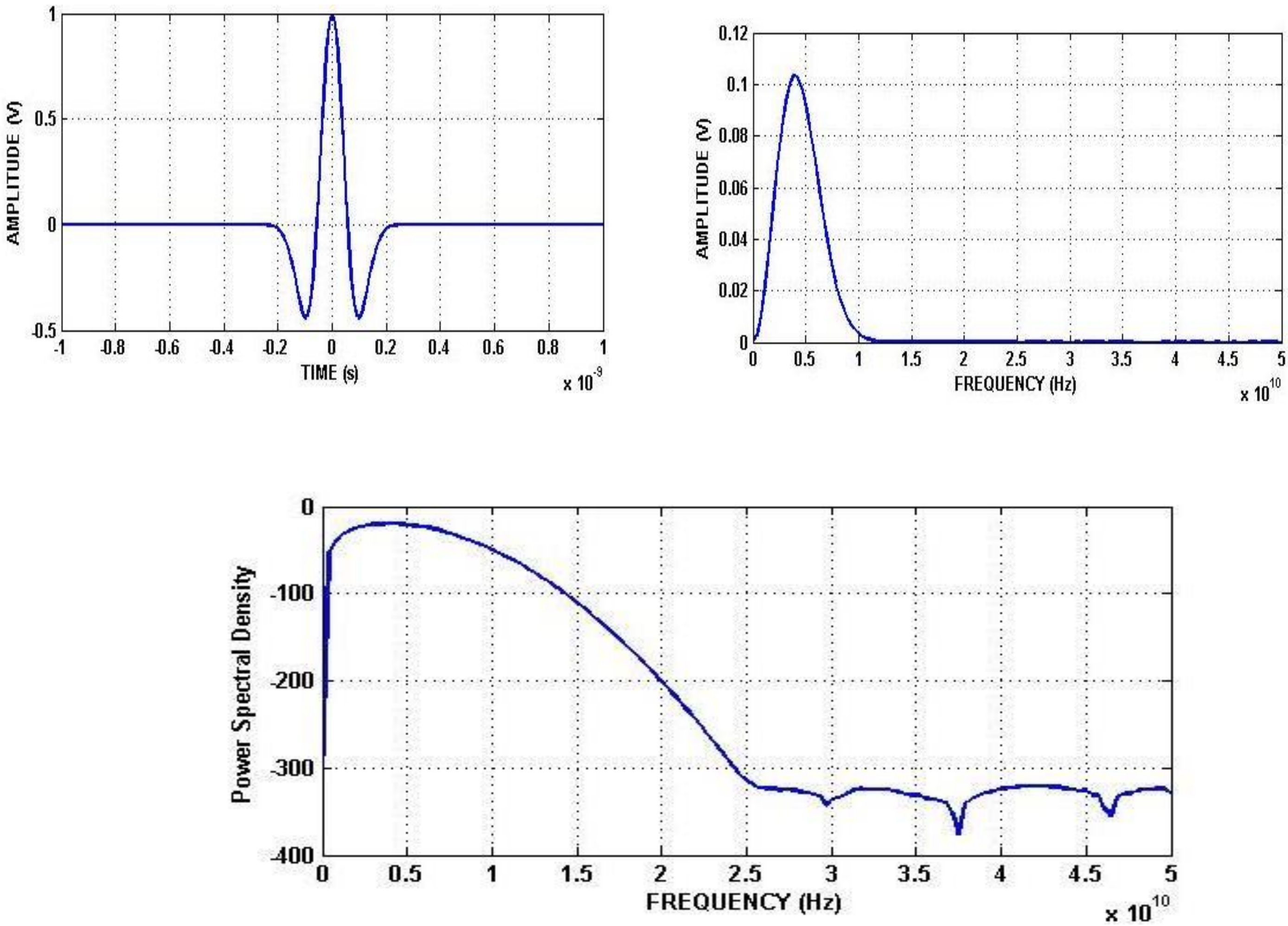


Figure 2.3: Gaussian doublet in time, frequency domain and power spectral density

2.2.4 Truncated sinus:

The truncated sinusoid is also often used. It proves to be convenient for simulation and analyses in UWB systems. Its expression is given by following equation

$$x(t) = \begin{cases} f(t).\sin(\omega_r t), 0 \le t < NT \\ 0, Else \end{cases}$$

(2.6)

$\omega_r = \dfrac{2\pi}{T}$ Pulsation

N: The number of cycles per period T.

f(t): truncation function (rectangle, triangle, Gaussian...)

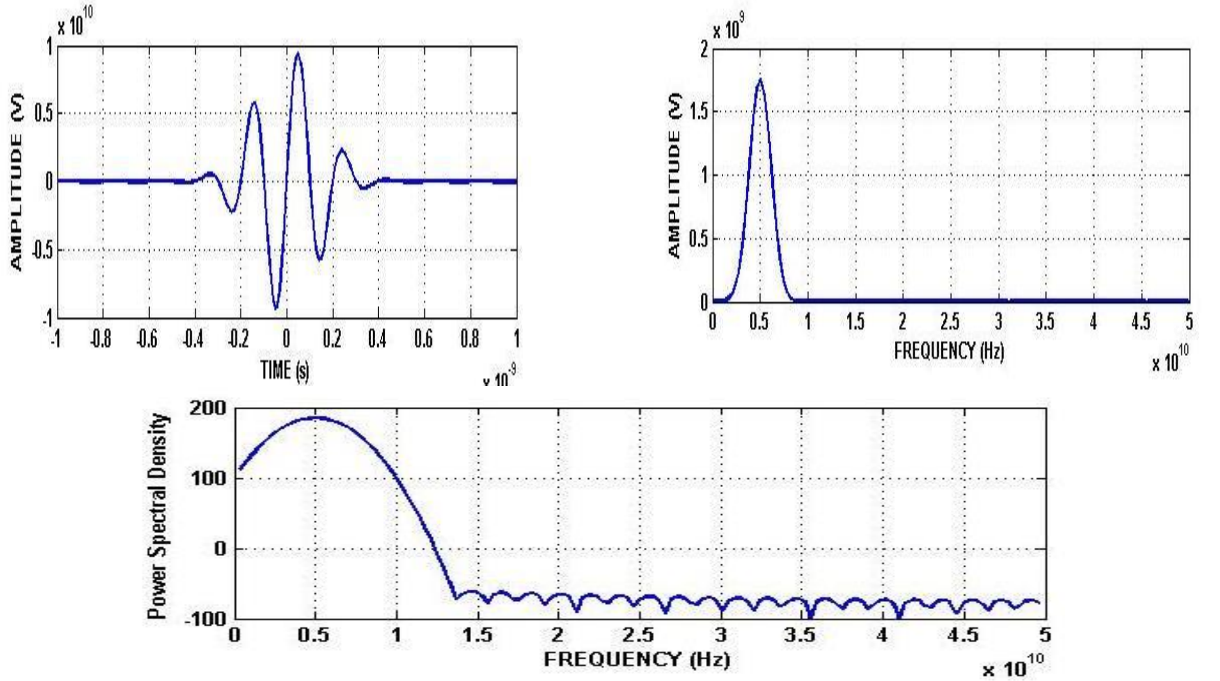


Figure 2.4: Truncated sinusoidal pulse in time, frequency domain and power spectral density

2.2.5 Orthogonal polynomial based pulse:

Modified Gegenbauer Functions (MGF) based impulse also found very good application in UWB system. They are well suited due to theirs orthogonally and multiplexing capabilities [3]. The Gegenbauer polynomials use the weight function $w(x) = (1 - x^2)^{(\beta - \frac{1}{2})}$ where, $\beta > -1/2$ is a wave shape parameter. MGF polynomials are orthogonal in the interval [-1,1]. Where n is the degree of polynomial. Following equations shows the first two orders of MGF polynomials:

$G0 = 1$

$G1 = 2\beta x$

$G2 = (-\beta + 2\beta(1+\beta)x^2)$

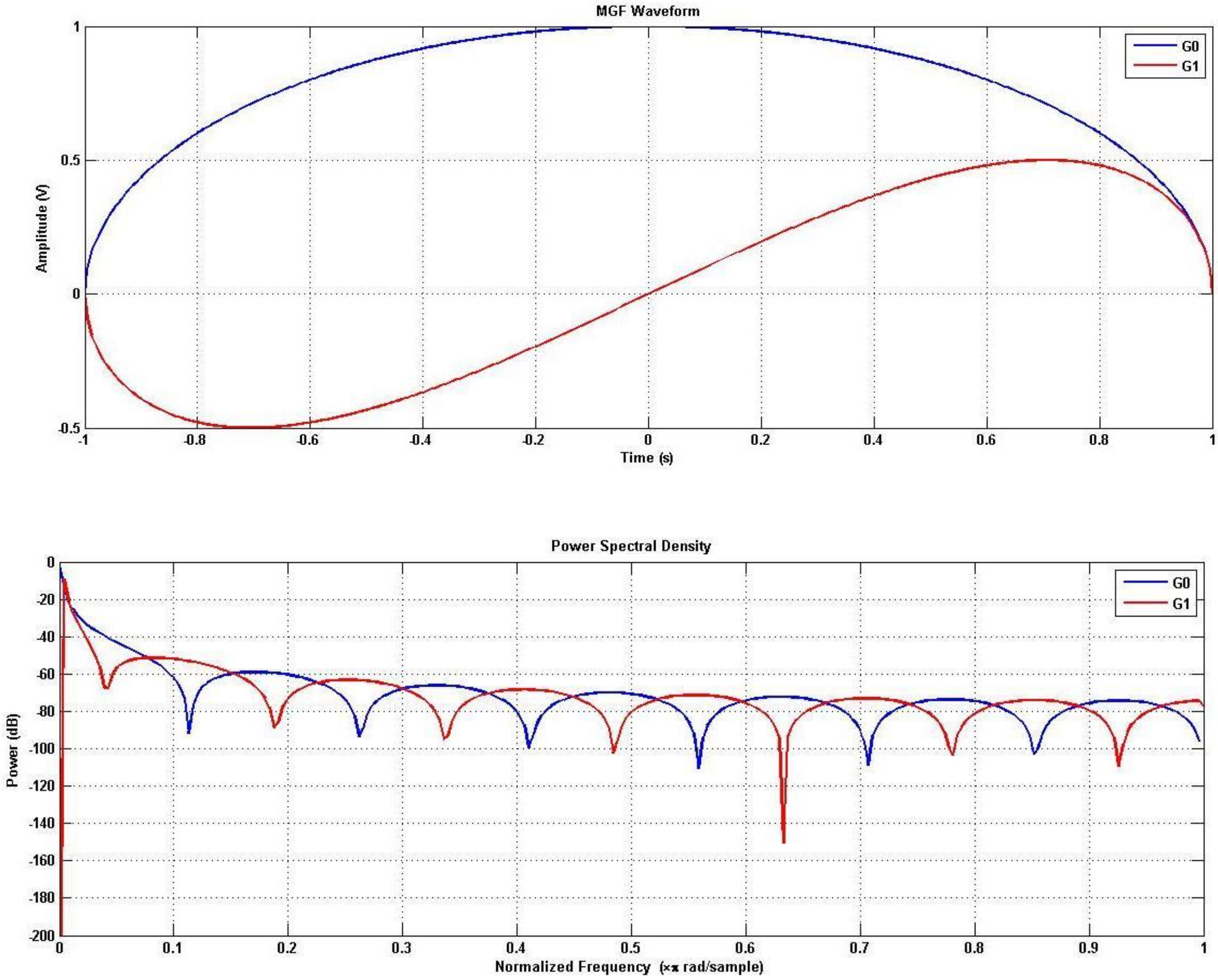


Figure 2.5: MGF function in time domain and power spectral density

2.3 UWB CHANNEL MODEL

The propagation environment through which message signal passes from transmitter to receiver is referred as channel. In UWB communication system accurate designing of channel model is a very important issue [27]. Indoor and outdoor channel modelling and propagation effects need to be carefully examine before implementation of UWB systems. Channel models should provide facility for calculation of large and small-scale statistics [17] and [33]. Specifically large-scale models are necessary for network planning and link budget design and small-scale models are necessary for efficient receiver design. The most famous multipath UWB indoor channel models are tap-delay line Rayleigh fading model, Saleh and Valenzuela (S–V) model and Δ-K model. The S–V channel measurement shows that the multipath components are arriving in a cluster form [34]. The different paths of such wide band signal can rise to several multipath components, all of which will be part of one cluster. The arrival of multipath components is modelled by using Poisson distribution and thus the inter arrival time between multipath components is based on exponential distribution. The multipath arrival of UWB signals are grouped into two categories: cluster arrival and ray arrival within a cluster. This model requires several parameters to describe indoor channel environments [35]. Ray arrival rate is the arrival rate of path within each cluster. The cluster arrival rate is always smaller than the ray arrival rate. The amplitude statistics in S–V model are based on lognormal distribution, the power of which is controlled by the cluster and ray decay factor [36]. Indoor channel environments are classified as CM1, CM2, CM3, and CM4 following IEEE 802.15.3a standard based on propagation conditions as follows [37].

- CM1 describes a line-of sight (LOS) scenario with a maximum distance between transmitter and receiver of less than 4m.

- CM2 describes the same range as of CM1, but for a non-line-of sight (NLOS) situation.

- CM3 describes a NLOS medium for separation between transmitter and receiver of range 4-10m.

- CM4 describes an environment of more than 10m with strong delay dispersion, resulting in a delay spread of 25ns with NLOS medium.

In this research work we have to design UWB based communication system model for railway tunnels. Main problems associated with tunnel environment are heavy multipath, frequency selectivity and distance dependent path loss, so we can not simply implement the above discussed UWB indoor channel model to our project. We have considered the geometrical ray model for UWB propagation [1].

2.4 APPLICATIONS OF UWB SYSTEM

The various applications of UWB technology has include both commercial and military side on the basis of high data rate communication, short range applications, remotely sensing radar, vehicular radar and multimedia devices. UWB technology has major role in three wireless application areas: communications, radar and positioning or ranging [7].

A. Communication System:

- Tremendously large available bandwidth makes possible to establish a very high data rate short range wireless local area network, of the order of gigabits per second. Since UWB bandwidth spreads at very low frequencies so effect of attenuation due to environment and path losses are very low.
- UWB associates various computer peripherals, where mobility is important and a number of wireless devices are utilized in a shared space. A mouse, keyboard, printer, monitor, audio speakers and microphones are in wireless, all attached to the same computer and sending messages within a given range.
- In medical applications, UWB wireless sensor network gives freedom to patient from wired sensors. UWB sensors can observe pulse rate, temperature and other critical life sign in a patient with a very effective manner.
- UWB system based on the short duration pulses which are immune to multipath cancellation, so it’s found a very good place for the multiuser network applications.

B. Radar System

- Large bandwidth and short pulses provides very fine resolution, precision distance and positioning measurement, for radar applications. Also use of short pulses in

UWB system avails better immunity to the interference due to rain, fog, aerosols, etc. and ability to detect very slowly moving or stationary targets.

- UWB signals makes feasible to design inexpensive high definition radar which could be used in areas like automotive sensors, smart airbags intelligent highway initiatives and personal security sensors.
- In vehicular technology, in the range of 22 to 29 GHz band UWB based radar can be used to detect the location and movement of the objects near a vehicle to avoid the possible collision. These devices enable the features such as auto navigation, collision avoidance, improved airbag activation, intelligent suspension systems, etc. This application is very important for safety purpose in railway transportation.

C. Positioning Systems

- There is a direct relationship between bandwidth and precision. Larger bandwidth provides the highly precise positioning. UWB full fills both the requirements.
- UWB improves the performance of obstacle detection radar precision geo-location systems, proximity fuses and secure ground communications for military troops.

2.5 SUMMARY

This chapter presented overall aspects of UWB communication system. Background and definition of UWB technology presented in brief. Advantages of UWB have been discussed, which makes it a prominent tool for wireless communication. Various UWB pulse shapes described along with equations and their representation in time and frequency domain. UWB channel model and applications of UWB systems described briefly.

Chapter 3

Wireless Communication Systems for Railway Transportation

Chapter 3

Wireless Communication Systems for Railway Transportation

3.1 INTRODUCTION

Advancement in communication technology makes possible to apply wireless communication techniques in almost all sectors for the transmission of information in all forms between any two points. Wireless communication system finds a very promising role in railway transportation system as it can reduce the maintenance and inspection requirements of railway systems while maintaining safety and reliability. Since in this modern age, railway infrastructure is developing very rapidly. So to accommodate the requirements of growing system past wired communication systems for signalling and data transfer is replaced by latest wireless communication systems. Operational railway communication network can be classified into three groups as locomotive, wayside and train control network. The requirements of an efficient railway communication network can be illustrated as [9]:

- It provides uninterrupted communication between drivers and signallers at any time any place.
- Drivers get alerts about any potential hazards well before in time.
- In an emergency, drivers can communicate quickly with signallers and control station.
- Signallers are aware about the location of train on the track.
- It should reduce the incidents of faulty signalling and failure to control the train.
- Timely and accurate information about train schedule should be available to the passengers.

When trains run on railway tracks they follow rules of operations in which safety plays a very important role. The most important rule in respect of safety is ensuring that two trains do not occupy the same position on the track at the same time [12]. To make this rule work operation of trains uses signalling to control movement of trains on tracks and divides tracks into several sections which are protected by the signals. Simultaneously the drivers maintain contact with controller for updating the traffic status and possible changes in route. Signalling and communication technologies developing continue and providing safer, faster mode of information exchange.

3.2 COMMUNICATION AND SIGNALLING SYSTEMS FOR RAILWAY CONTROL

Maintaining Safe distance between trains is the most important safety precaution for railway transportation. This safe distance is decided by the current train location, its relative speed to other trains in the same area, and the other trains locations and directions of movement. A large number of signalling strategies have been developed over the past years, to maintain the safety. Some of the current methods of signalling and train control systems are [9], [20] and [21]:

- Communications-Based Train Control (CBTC) Systems
- Advanced Train Control Systems (ATCS)
- Command Control and Communications Systems (CCCS)
- Incremental Train Control Systems (ITCS)
- Positive Train Control (PTC),
- Positive Train Separation (PTS)
- European Train Control System (ETCS)
- Global System for Mobile communications version for the rail industry (GSM-R)
- Terrestrially Trunked Radio (TETRA)
- Enhanced position and location reporting system (EPLRS)

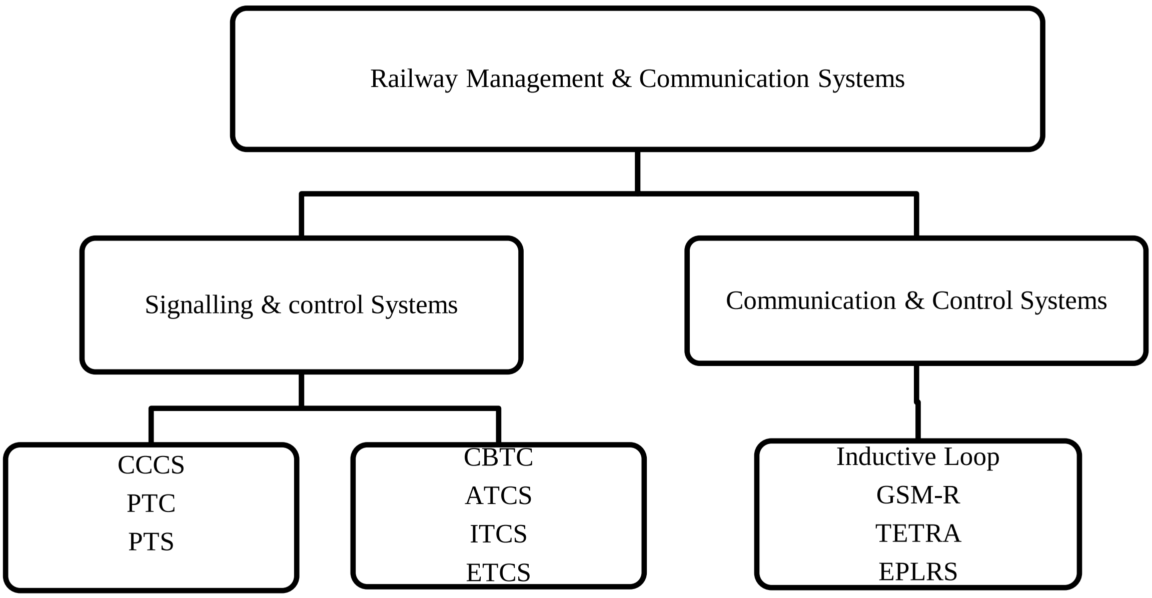


Figure 3.1: Signalling and train control systems [9]

Out of those signalling and train control systems Communications-Based Train Control (CBTC) Systems and Advanced Train Control Systems (ATCS) are explained below as these two systems are widely used.

3.2.1 Communications-Based Train Control (CBTC) Systems

Communication based train control (CBTC) systems emerged as dominating technology in the railway industry. Implementation of CBTC provides two way continuous communications which increases line capacity and enables more flexible train operations. Furthermore CBTC ensures a higher level of safety. In order to guarantee system availability it is crucial that every single connectivity component in the data communication system continues to operate regardless of external factors such as environmental, mechanical or operational constraints. These things can be achieved through control and telemetry data interchange between trains and wayside operators. CBTC provides following functions:

1.) Automatic Train Protection (ATP) functions:

ATP is a train safety system. It uses trackside and on-train equipment to identify some potentially unsafe conditions, and if necessary the on-train equipment will warn the Driver, and slow or stop the train before the conditions can become dangerous. Four specific functions of the system are to:

- Enforce track speed limits
- Give Drivers advance notice about the track ahead such as signals a STOP and track speeds
- Prevent trains from approaching a signal at STOP at too great a speed
- Prevent trains from passing the overlaps beyond signals at STOP.

2.) Automatic Train Operation (ATO):

Automatic Train Operation (ATO) insures partial or complete automatic train piloting and driverless functionalities. The ATO system performs all the functions of the driver, except for door closing. The driver only needs to close the doors, and if the way is clear, the train will automatically proceed to the next station.

3.) Automatic Train Supervision (ATS) functions:

ATS includes routing, schedule adherence and fault monitoring functions. With the help these three functions CBTC systems ensure communication availability and if there is any communication loss, it is disrupted and stops the trains. Over time the CBTC system has been equipped with wireless communication systems and incorporates a radio frequency (RF) technology.

3.2.2 Advanced Train Control Systems (ATCS) [23]

ATCS is a closed loop, distributed control and communication system using advanced computers and digital data communication. ATCS is the application of modern command, control and communications technology to a line constrained transportation system. In the ATCS design the dispatch or operations computer(s) are connected through the data communications network to computers on board the locomotive, in track forces vehicles and in wayside interface units which control and/or monitor field devices such as switches and hot box detectors. The train speed and location system relies upon in track transponders, or alternatively signals from global positioning satellites, and locomotive odometers. This allows for precise train control, thus reducing headways, improving conflict resolution and improving train safety. ATCS is an open standard for RF data systems used to ensure seamless operation and interoperability between different railway systems. ATCS is based on international standard organization's (ISO) open system interconnect (OSI) model and transmits over radio waves using full-duplex 900-MHz channels at 5800 baud. ATCS has five major subsystems, which are:

- Central Dispatch System (CDS)
- On-Board Locomotive System (OBLS)
- On-Board Work Vehicle System (OWVS)
- Data Communication System (DCS)
- Wayside Interface Units (WIUs)

ATCS has drawback that it is lack of encryption technology which allows spoofing or false command injection and also vulnerability to jamming. This drawback can be overcome by using symmetric key encryption system.

3.3 WIRELESS COMMUNICATION INSIDE RAILWAY TUNNEL

The above discussed railway signalling and communication systems are mainly used in urbanized areas and urban railway transportation is mainly operated in underground tunnels. Railway tunnels are very critical and important part of the railway track as safety requirement increases, when a train passes through the tunnels. In such cases we need fast and reliable mode of communication, as previously discussed that at present wired communication has totally replaced by the wireless communication system. To develop a setup of wireless communication system for tunnel it is necessary to study about the radio wave propagation in tunnel. Natural propagation of electromagnetic waves is the simplest method to establish a radio link in an underground tunnel. Nowadays, the problem of radio communication in tunnels has found solutions using leaky transmission lines as supports for propagation of transverse electromagnetic modes. These modes are characterized by the fact that there is no cut-off frequency, and by an attenuation which increases with increasing frequency. However, when the frequency is high enough, natural propagation modes, which are transverse electric or transverse magnetic, can appear and interfere with the transmission-line-supported transverse electromagnetic modes [25].

Tunnels can be considered as hollow conductors which will work as a waveguide. Waveguides are the guided transmission lines in which wave travels by using the phenomena of total internal reflection. Waves travels through waveguide in transverse electric or transverse magnetic modes only when frequency is higher than a certain cut-off frequency. The values of these cut-off frequencies depend on the given mode, and are also determined by the shape and the transverse dimension of the gallery. Expression for cut-off wavelength for rectangular waveguide (as we have considered the rectangular tunnel), is

$$\lambda_{mn} = \frac{2\sqrt{ab}}{\sqrt{m^2 \frac{b}{a} + n^2 \frac{a}{b}}} \tag{3.1}$$

Where a is the width of the guide and b is the height, and m, n are the integers decides the mode of propagation. Its values are 1, 2, 3… for the TM_{mn} modes, and equal to 0, 1, 2, 3, for the TE_{mn} modes.

3.4 SUMMARY

This chapter presented the already implemented wireless based railway signalling and controlling systems. Two most commonly used communication and control systems, CBTC and ATCS described in brief. In section 3.3 mechanism of wave propagation inside tunnel is discussed.

Chapter 4

UWB Communication System for Railway Tunnels

Chapter 4

UWB Communication System for Railway Tunnel

4.1 INTRODUCTION

Railway transportation is in existence from around 250 years [22]. Rail transport is a mode of commuting passengers and goods over a guided metal tracks. It's a very efficient and economical transportation as it can move heavy loads and traffic at high speed over long distances. Millions of people all over world depend on it for their daily needs, because of this railway transportation requires very safe and reliable mode of control and signalling systems. As we have discussed earlier that in past, wired technology was used for smooth operation of trains. Some of the protection issues are discussed below:

- As we know that train traverse on fixed guided track, so sudden change in route is not possible, so in case to avoid obstacles we must need to aware well before in time. It could be possible by implementing well developed obstacle detection system [4].
- Operation of multiple trains on the same rails in opposite direction may cause collisions. So we need a traffic system which maintains the rules of right occupancy on the track.
- Interruption in communication between train drivers and controllers may cause the loss of control over the train. So we need a fast and reliable system for data transmission.
- Localization of train at any time any point on the track so that passengers can get timely updated information about the train running status.

In past, various detection and communication systems were used to detect the obstacles on the track and to avoid the collision. Examples are electrified slide fences, use of light beams and photo-detectors, seismometers [4] etc. but these systems were not much accurate as they depend on some foresight and also their installation cost was very high, that they cannot employed throughout the railway track.

Now those wired signalling systems are replaced by the wireless communication and signalling systems. This enables to enhance the safety and efficiency of railway management. Ultra wide band radio based wireless communication emerges as a rapid growing technology which has tremendous capability of simultaneous train to wayside communication, train location and obstacle detection and data transmission with high data rate [5]. The UWB based signalling system is very effective for urban transport systems which are mainly operate inside underground tunnel. Underground transportation systems are maintained by control and command centres. Role of control and command centers are to collect the information about the vehicle from their source to destination. Some very important information to collect are location of train, speed, acceleration and condition of vehicles. The most popular and practically implemented control and command system is communication based train control (CBTC), which has discussed previously. For efficient and smooth functioning of railway system, effective and highly available train to track communication system is must. Day by day increasing traffic and amount of data transmission creates problem to maintain an efficient train to wayside communication. Performance of existing communication systems are limited by the harsh environmental and construction problem related with tunnel and urban transportation. According to propagation phenomena this environment conditions can be characterized as multipath fading effect, frequency selectivity, distance and frequency dependent pathloss. Conventional narrow-band communication systems are severely affected by these propagation characteristics, so it is replaced by the large-bandwidth communication system [5]. These problems associated with the propagation of waves inside railway tunnels has been studied in the project and explained in detail in this thesis, by using UWB radio based wireless communication system. As we have already discussed about UWB communication system in previous chapter, so we know that UWB provides accurate ranging and very high data speed beyond 480 Mbit/s within range of ten meter [3].

4.2 ULTRA WIDEBAND CHANNEL CHARACTERISTICS

Channel is a medium through which message convey to one or many receivers from the transmitter. It could be wired or wireless, having a fixed capacity of data transmission. In any communication system channel is a very important part as channel characteristics decides the propagation characteristics and quality of transmission and reception. Before studying the design consideration of a UWB communication system, it is important to understand about the ultra-wideband propagation channel. So first it is good to be aware of the fundamental properties of UWB channels, and how it is different from those conventional narrow band channels [10]. UWB system has relatively very large bandwidth hence the propagation process, path loss and shadowing effect become frequency dependent. Fundamental properties of UWB propagation are:

1. **Multipath Propagation:** Multipath waves are the multiple versions of transmitted signal that arrives at the receiving antenna. A single transmitted signal split into multiple components because of reflection, diffraction and scattering from various environmental objects like mountains, houses, trees, walls etc. these multipath component could be different in phase and amplitude from the actual one. The random change in phase and amplitude of the different multipath components cause fluctuations in signal strength, which produces small scale fading effect and/or signal distortion. Since the multipath components traverse through different path so depending upon the length of path, time delay of arrival increases which may cause inter symbol interference. The signal at receiver side can be represented as the sum of scaled and delayed replicas of the transmitted signal and the channel impulse response can be represented mathematically as

$$h(t) = \sum_{i=1}^{N} a_i \delta(t - \tau_i) \tag{4.1}$$

Where a_i is the gain and τ_i is the time delay of multipath components. The above equation for channel impulse response based on some limitations, as objects causes to produce multipath components may be time variant but equation is not including those factors. Also it's not including the frequency dependency of multipath components which are very important for UWB propagation channel. For example; reflection coefficient of tempered glass changes from 0.9 to 0.65 with change in frequency from 7.5 to 10.5 GHz [10]. After including this frequency dependency of multipath components the modified channel impulse response can be written as:

$$h(t) = \sum_{i=1}^{N} a_i \chi_i(t) \otimes \delta(t - \tau_i) \tag{4.2}$$

2. **Large Scale Fading:**

   Wireless communication channel are random in nature to analyse their characteristics and predict the possible change is not easy. In wireless channel radio waves propagate through three basic mechanism called reflection, diffraction and scattering. Since open air contains so many stationary and dynamic objects so the waves travels along different path, which causes to decrease in signal strength. When this happens for short transmitter receiver distance it is called as small scale fading and when the distance between transmitter receivers is the order of several thousands of meters then decrease in signal strength is due to large scale fading [26]. Small scale fading causes because, received signal is a combination of multipath components which are delayed version of original signal with random phases. Large scale fading is the attenuation of signal due to obstacles in propagation path over a long distance [10]. In large scale propagation model waves propagated by following three mechanisms:

   Reflection: It is the change in direction of radio wave when it impinges upon interface between two different mediums in such a way that incident waves return to the same medium from which it is coming [27]. For reflection to be occurs dimension of obstacles should be very large when compared with wavelength of propagated radio wave [26].

   Diffraction: Diffraction is the phenomena in which electromagnetic wave spreads out after striking the surface which has sharp edges or by passing through a narrow aperture. A secondary wave generated behind the obstacle, which cause bending of transmitted wave around the obstacle [26]. Here for diffraction, size of obstacle or gap should be same as the wavelength of electromagnetic wave.

Scattering: Scattering means the dispersion of electromagnetic wave into various direction, when it passes through a medium which consist of objects with dimension very small than the wavelength of transmitted wave. Scattered wave produces by rough surfaces, small particles and other irregularities in channel [26].

1.3 RAY THEORY MODEL OF PROPAGATION [27]:

Path loss is a very important parameter for designing a wireless channel, as it used to evaluate large scale fading effect which in turn determines the small scale fading characteristics of the channel. Path loss plays an important role in link budget analysis which calculates the attenuation over the travelled distance and also cost of transmission. Path loss can be modelled from power law dependence with distance from transmitter $L_p = ad^{\gamma}$ and to accommodate the shadowing phenomena, a random variable with log normal distribution added to the average path loss which takes care of fading effect.

Usually we ignore the path loss frequency dependence while modelling a UWB propagation channel because it has negligible effect over the frequency range of current wireless communication systems. But this assumption cannot be applied universally to UWB systems. So here we are going to study the two ray model for path loss over short ranges. Since the available conventional narrowband plane earth model are not useful so two ray link is evaluated for as a function of both frequency and distance. Considering the specific UWB application for railway tunnel, the analysis is carried out up to the distance of 55 meters within the operational frequency range of 3.1 GHz to 10.6 GHz.

According to definition a two ray propagation model contains the direct ray and the ground reflected ray, as illustrated in figure 4.1

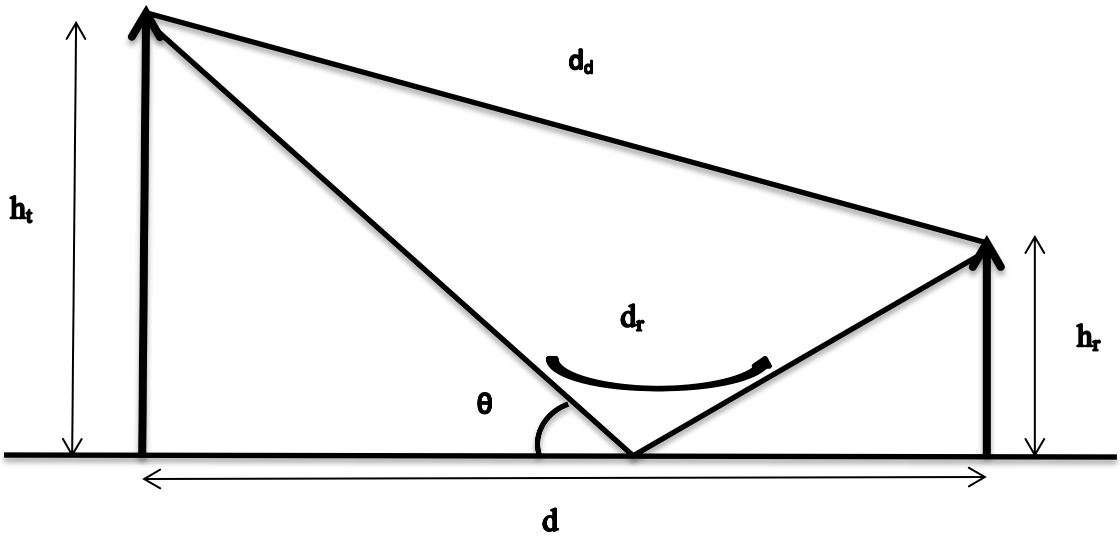


Figure 4.1: Two ray model including a transmitter and a receiver [27]

Figure 4.1 shows the two ray propagation model where h_t and h_r are the height of transmitter and receiver respectively. Direct ray and ground reflected ray represented by d_d and d_r respectively and d is the separation between transmitter and receiver. Actual practical channel model contains several multipath components but the basic analysis of considered channel model will be done on the basis of this above said two ray theory. We will proceed by considering that received electric field is the result of superposition of two rays and path loss is expressed as $L_p = (G_p)^{-1}$, where path gain G_p is represented as [27]

$$G_p = \left(\frac{\lambda}{4\pi}\right)^2 \left| \frac{e^{-jkd_d}}{d_d} + \frac{R_{H,V} e^{-jkd_r}}{d_r} \right|^2 \tag{4.3}$$

Where,

$k = \frac{2\pi}{\lambda}$; Free space propagation constant

$\lambda = \frac{c}{f}$; Free space wavelength

c = speed of light

Length of rays for line of sight and non-line-of-sight is derived from the figure by considering the image theory

$$d_d = \sqrt{d^2 + (h_t - h_r)^2} \tag{4.4}$$

and

$$d_r = \sqrt{d^2 + (h_t + h_r)^2} \tag{4.5}$$

Fresnel reflection coefficients for horizontal and vertical polarization are defined as

$$R_H = \frac{\sin\theta - \sqrt{\in_r - \cos^2\theta}}{\sin\theta + \sqrt{\in_r - \cos^2\theta}} \tag{4.6}$$

and

$$R_V = \frac{\in_r \sin\theta - \sqrt{\in_r - \cos^2\theta}}{\in_r \sin\theta + \sqrt{\in_r - \cos^2\theta}} \tag{4.7}$$

Where

$$\varepsilon_r(f) = \varepsilon_r^{'}(f) - j\,\frac{\sigma(f)}{2\pi f \varepsilon_0}$$

(4.8)

The above equation is for dielectric constant of the reflecting surface, for appropriate characterization of UWB propagation we must consider the frequency dependency of relative permittivity $\varepsilon_r^{'}(f)$ and the conductivity $\sigma(f)$ over the UWB frequency range.

4.4 COMMUNICATION SYSTEM MODEL

Any communication system consists of three basic components transmitter, receiver and most important one channel. Here we are studying a communication setup for railway signalling and control system by using UWB technology. As we have discussed both the small scale fading and large scale fading effect for UWB signal propagation considering railway tunnel as an oversized waveguide in which message signal propagated by multiple reflection gives rises to multipath components. Ultra wideband communication system can be classified as pulse based or multicarrier based communication [29]. Multicarrier based UWB system uses OFDM technique, with orthogonal carriers like modified Gegenbauer polynomial, modified Hermite polynomial for data transmission [30] and [31]. Here we are mainly focusing on carrier less UWB system, so we will consider the single link UWB communication system for the sake of simplicity. The basic block diagram for UWB communication system for railway tunnel to wayside communication is shown in figure

Figure 4.2 shows a complete communication system with all necessary components i.e. transmitter, receiver and wireless channel. Transmitter consists of source of data, UWB modulator, UWB signal generation and other basic part like filter and antenna array. In our case data are usually a voice message to convey to train driver or some kind of command signal to control the train operation.

Modulation is needed because one single UWB pulse does not contain any information so we add digital information to it by means of some modulation techniques [27].

Several methods of modulation are available which are classified as time based techniques and shape based techniques, shown in the figure

Pulse position modulation (PPM), delayed or sent in advance each pulses at regular time interval, so binary communication can be perform with forward and backward shift in time. Bi phase modulation (BPM) or more specific binary phase shift keying (BPSK) converts the pulses into opposite phase, while in on-off keying (OOK) absence (0) or presence (1) of pulses defines the digital information. Pulse amplitude modulation (PAM) varies the amplitude of pulses to transmit the digital information [27]. One more advanced modulation technique is orthogonal pulse modulation (OPM) which is also a type of pulse shape modulation with the characteristics that pulse shapes are orthogonal to each other. OPM is used for multiple accesses in UWB communication system. Here the modulated data transmitted through a wireless channel. We assumed the railway tunnel as multipath channel with added white Gaussian noise, and has already discussed about UWB propagation characteristics i.e. small scale fading and large scale fading effect. The considered channel is frequency selective in nature. At the receiving it consists of a filter, a low noise amplifier and a receiver. UWB signal mainly detect by correlator receiver or Rake receiver. Correlator receiver is a set of multiplier and integrator which compares the received signal with the reference signal and tells about how much it resembles the original transmitted signal. Rake receiver consists of several branches of correlators. Since UWB channel suffers from multipath fading so rake receiver is used to improve the reception quality by adding up these multiple versions of transmitted signal in a constructive way. But it increases the complexity of circuitry.

4.5 SUMMARY

This chapter concludes the requirements to design an UWB radio based wireless communication system for railway tunnel. It explained the two important UWB channel characteristics i.e. multipath propagation and large scale fading, designed channel going to be analyse on the basis of these two characteristics. It described the ray theory model of propagation with their necessary mathematical descriptions. This chapter represented the block diagram of general UWB communication system along with common UWB modulation techniques.

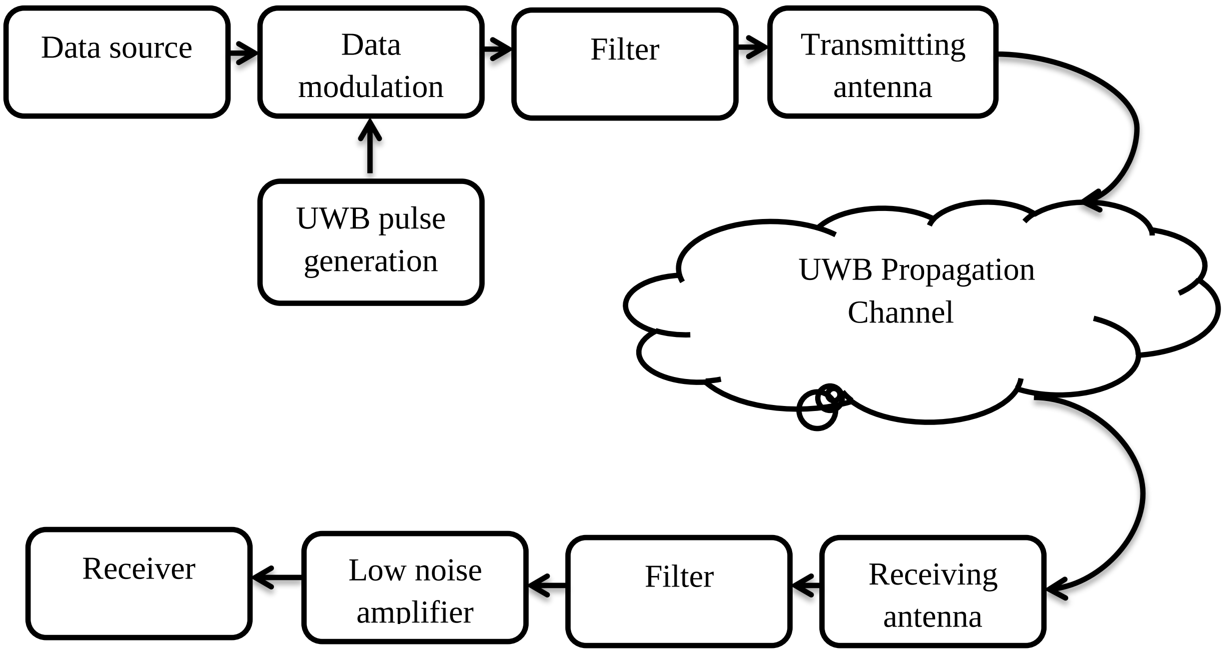


Figure 4.2: UWB communication system model [15]

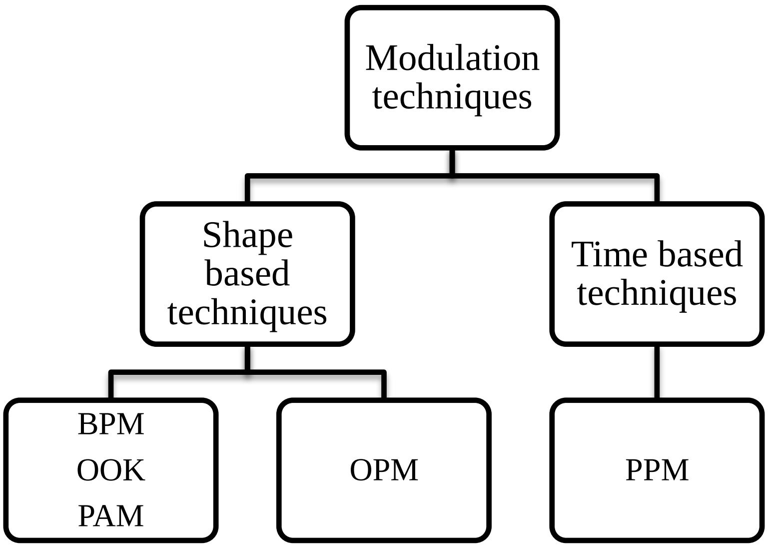


Figure 4.3: UWB modulation techniques [27]

Chapter 5
SIMULATIONS, STUDY & RESULTS

Chapter 5
SIMULATIONS, STUDY & RESULTS

5.1 SIMULATIONS AND STUDY

5.1.1 MODEL OF UWB PROPAGATION CHANNEL IN TUNNEL

Modern railway transportation is mainly operated under tunnel. Tunnel environment provides severe attenuation to the narrowband communication system as it suffers from frequency selectivity, heavy multipath due to reflections from the surfaces of tunnel and signal attenuation along the tunnel depending on the distance between transmitter and receiver and used frequency [3], [5] and [8].

So UWB radio communication has the capability to perform well under above said situations because of its very large bandwidth. Rectangular shaped tunnel (figure 5.1) is considered as an oversized waveguide because tunnel size is much large in comparison with our operating wavelength (10 to 3 cm). The basic ray theory model has been considered to evaluate the channel responses. The tunnel can be look as a multipath channel with added white Gaussian noise. We have assumed that channel is static and time invariant since we have considered the short distance propagation. So

$$h(t) = \sum_{i=1}^{N} a_i \exp(j\theta_i)\delta(t-\tau_i) \tag{5.1}$$

Where;

a_i is the amplitude of i^{th} path

τ_i is the delay of i^{th} path

θ_i is the phase value of i^{th} path

N is the number of resolvable multipath

This research includes the theoretical study of tunnel channel model considering it as deterministic in nature over the UWB frequency range of 3.1 GHz to 10.6 GHz. So the equivalent channel impulse response and the frequency response has been evaluated by using following equations [8]

$$E_{tot} = \sum_{\{f_{\min}, f_{\max}\}} E_0 \frac{\lambda}{4\pi} \sum_{n=0}^{N-1} \frac{e^{-jkd_n}}{d_n} R_V^{\alpha} R_H^{\beta} \tag{5.2}$$

$$h(t) = F^{-1}\left\{\frac{E_{tot}}{E_0}\right\} \tag{5.3}$$

Where,

E_0 = reference electric field
N= Number of resolvable multipath
k= wave number
$R_{V(H)}$= complex reflection coefficient on vertical(horizontal wall)
α (β)= number of reflections on the vertical (horizontal wall)
d_n=length of n^{th} ray

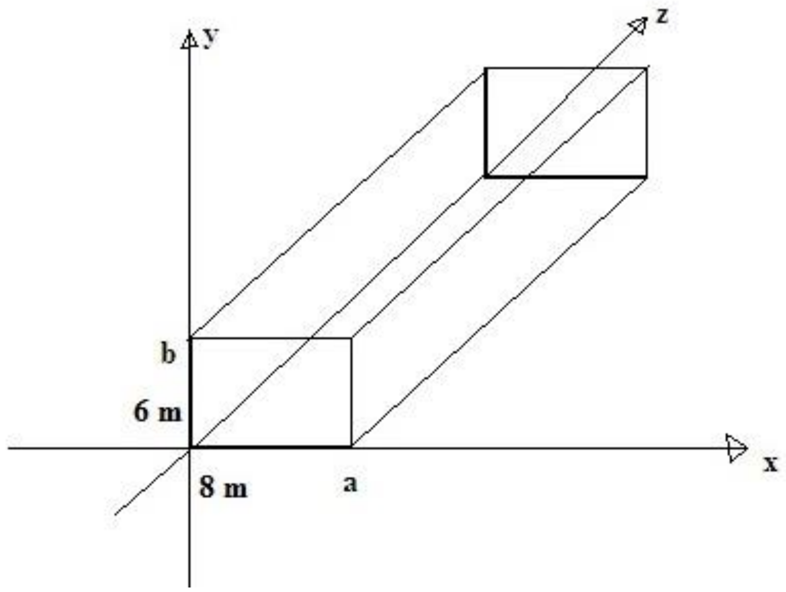


Figure 5.1: Rectangular Shaped Tunnel Model [5]

Channel characteristics have been studied by considering the following theoretical model and simulation setup shown in Figure 5.2. The transmitter is located at a particular place along the main axis of the tunnel. The receiver moves along the main axis of the tunnel from a reference distance (1 m) then starting from 5 m up to a given distance d_n. Here channel parameters estimated in the 3-10 GHz frequency band [8].

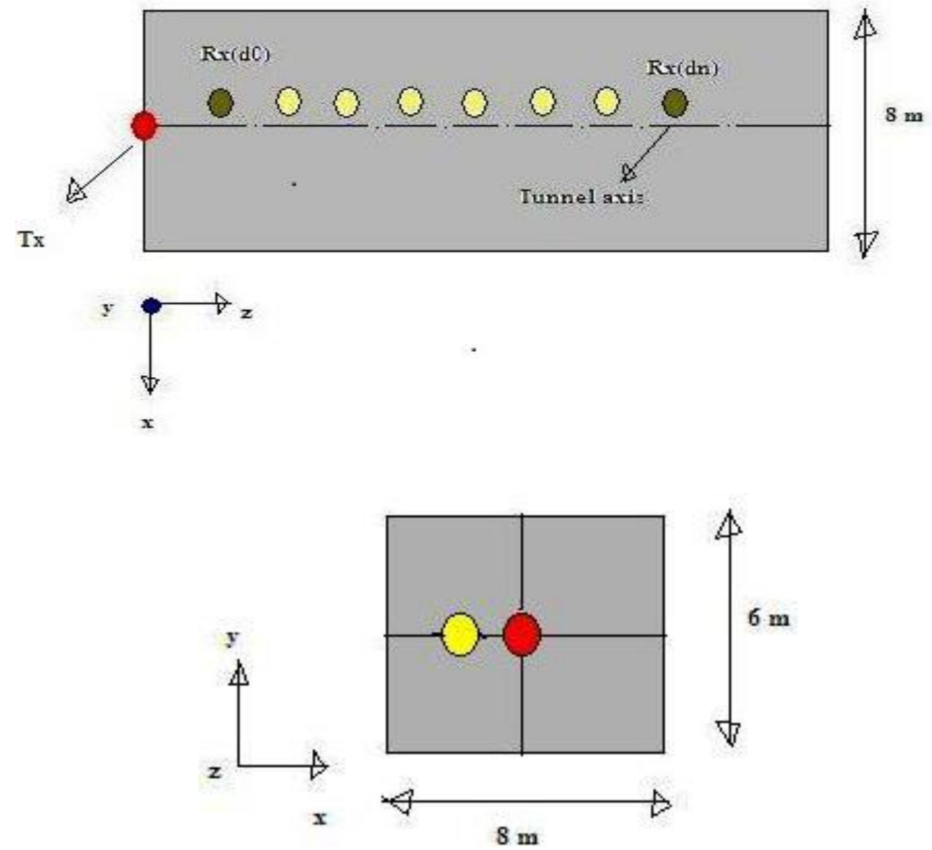


Figure 5.2: Simulation setup[5]

By writing the MATLAB program for following set of equations [3] and [5], channel model is evaluated over the Ultra wideband frequency range:

$$E_{tot} = \sum_{\{f_{\min}, f_{\max}\}} E_0 \frac{\lambda}{4\pi} \sum_{n=0}^{N-1} \frac{e^{-jkd_n}}{d_n} R_V^{\alpha} R_H^{\beta} \tag{5.2}$$

$$h(t) = F^{-1}\left\{\frac{E_{tot}}{E_0}\right\} \tag{5.3}$$

$$R_H = \frac{\sin\theta - \sqrt{\in_r - \cos^2\theta}}{\sin\theta + \sqrt{\in_r - \cos^2\theta}} \tag{5.4}$$

$$R_V = \frac{\in_r \sin\theta - \sqrt{\in_r - \cos^2\theta}}{\in_r \sin\theta + \sqrt{\in_r - \cos^2\theta}} \tag{5.5}$$

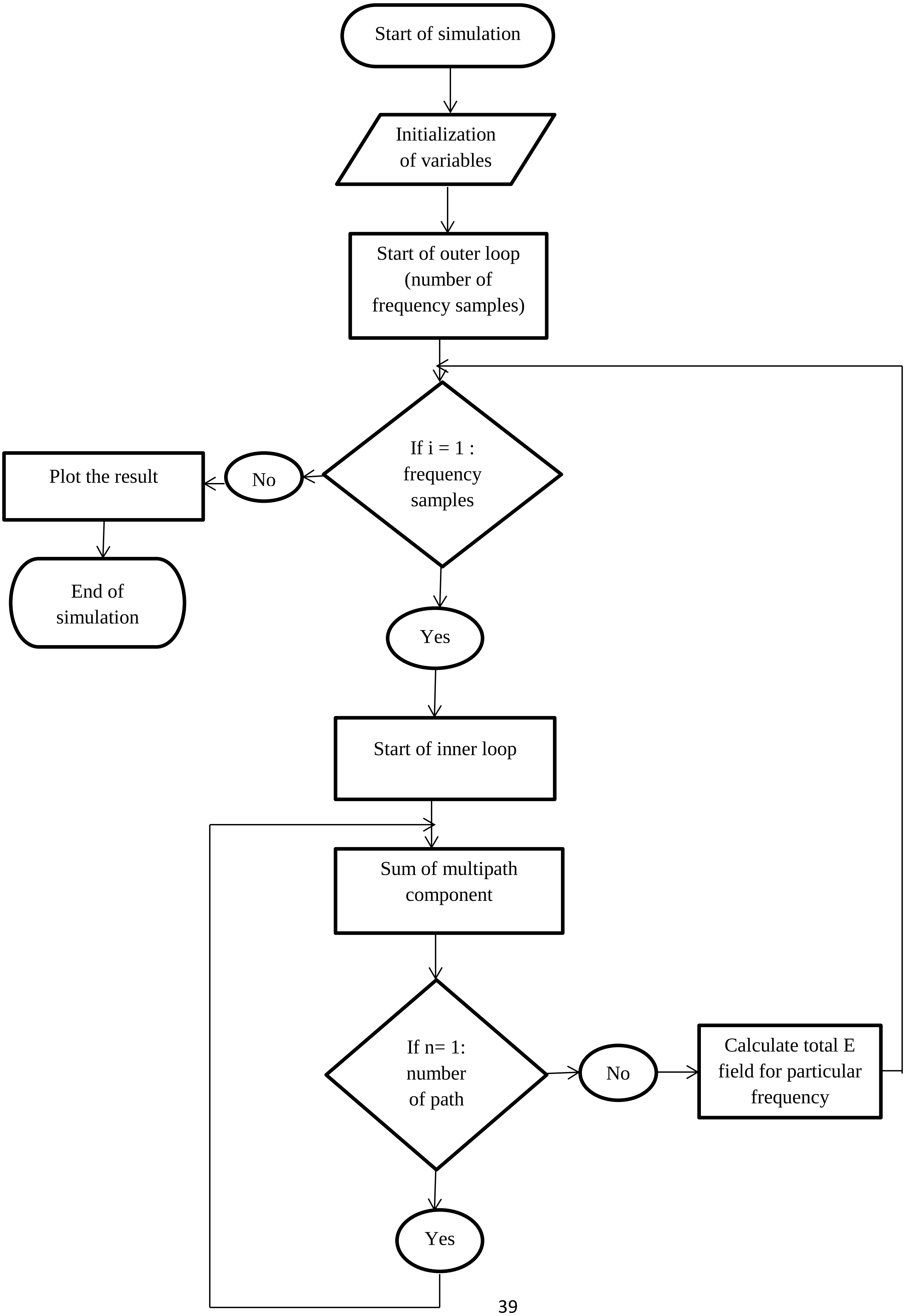
Table provides the channel parameter used for this evaluation

TABLE 5.1

CHANNEL MODEL PARAMETERS [5]

Parameter	Value
Frequency band	3.1-10.6 GHz (1601 samples)
Conductivity (S/m)	σ= 0.05
Permeability (H/m)	μ_r=1
Permittivity (F/m)	ϵ_r = 7
Tunnel size (b*a) (m)	6*8
Number of reflections(vertical wall)	α = 12
Number of reflections (horizontal wall)	β = 10
N (number of multipath component)	168+ direct path

Simulation using MATLAB is done according to following flow graph


Start of simulation
Initialization of variables
Start of outer loop (number of frequency samples)
If i = 1 : frequency samples
No
Plot the result
End of simulation
Yes
Start of inner loop
Sum of multipath component
If n= 1: number of path
No
Calculate total E field for particular frequency
Yes

5.1.2 WAVE PROPAGATION THROUGH CHANNEL

As mentioned before, that railway tunnel is considered as a multipath channel with additive white gaussian noise, whose impulse response is represented by equation (5.1)

Now the designed multipath channel's behaviour is analysed by propagating three UWB pulse shapes and then observing the effect on the shape of transmitted waveforms. Three different UWB wave shapes considered here are Gaussian impulse, Gaussian mono-pulse and truncated sinusoidal pulse, propagated through the channel (considering all wave shapes at center frequency of 1GHz) without using any kind of modulation techniques, for four (1m, 5m, 25m & 55m) transmitter-receiver distances.

By comparing transmitted and received pulses, time delay and phase delay provided by channel are calculated (shown below in table 5.2).

TABLE 5.2

PHASE SHIFT & TIME SHIFT

Distance (m) → ↓**UWB Pulses**	**1**		**5**		**25**		**55**	
	θ (degree)	**τ (ns)**	**θ (degree)**	**τ (ns)**	**θ (degree)**	**τ (ns)**	**θ (degree)**	**τ (ns)**
Gaussian impulse	34.16	5.43	134.80	21.45	130.91	20.83	-129.80	-20.66
Gaussian mono pulse	214.27	34.10	314.42	50.04	310.43	49.41	51.12	8.14
Truncated Sinus	-145.69	-23.19	-45.59	-7.26	-49.58	-7.89	51.62	8.22

Note: Positive sign- delay

Negative sign- advance

5.1.3 CHANNEL PERFORMANCE BASED ON BIT ERROR RATE

The small scale fading effect and path loss has been studied for the channel. Now for the same four different distances between transmitter and receiver, bit error rate performance has been evaluated over the considered channel model. In previous chapter we have discussed the various available UWB modulation schemes, while choosing modulation technique we thought of various criteria like data rate, simple to implement, immunity to interference and error performance [3]. So by keeping in mind all this criteria we have selected BPSK modulation as it requires less energy per bit and work effectively for weak SNR values. BER versus SNR graph has been plotted shown in figure 5.9. Figure shows four BER plots for 1m, 5m, 25m and 55m transmitter receiver separation. Because of distance dependent path loss and small scale fading effect degradation in channel performance is easily observable. For the distance up to 25 meter considered UWB channel shows acceptable performance while as we increase distance UWB channel performance start to degrade, because strength of electric field start to decreases rapidly along with distance. So we can conclude that UWB communication system for railway gives very good performance for shorter distances and to cover the larger distances we need to use intermediate equipment which could maintain the level of transmission and reception.

5.2 RESULTS

Figure 5.3 shows the small scale fading characteristics of the considered UWB channel model over a distance of 15 meter inside a tunnel, its cleary shows that the strength of signal changes rapidly over the UWB frequency range for different Tx-Rx distance. For short distances fades are fast and frequent as number of multipath components receievd at receiver increases but as we go for longer distance fades become less frequent because number of constructive rays decreases at receiver side, and hence strength of electric field decreases [3]. It shows that UWB channel gives best performance for short ranges but as we go higher in distance due to the frequency selectivity property and path loss, the channel response gets attenuated. Figure 5.4 shows the corresponding channel impulse reponses, which is a set of impulses due to multipath components, effect of distance is also clearly shown in the figure over the impulse strength. Figure 5.5 shows the average path loss over the entire frequency band, which is caluclated by following equation [5]

$$PL(d) = \frac{1}{M}\sum_{i=1}^{M}\left|H(f_i, d)\right|^2 \tag{5.6}$$

$H(f_i,d)$ is channel frequency response, M is the number of frequency components at used frequency band, channel frequency response is considered as

$$H(f, d) = K_H \frac{\lambda}{4\pi d}\exp(-ikd) \tag{5.7}$$

Some standard UWB wave shapes propagated through this modelled channel are shown in figure 5.6, 5.7, and 5.8. Since the considered channel is behave as multipath channel so we have studied that how much phase shift and time shift it provided to these standard UWB waveforms. Values of phase shift and time shift is shown in the table 5.2.

Figure 5.9 shows the bit error rate versus signal to noise ratio plot for the considered UWB channel using BPSK modulation technique for four different transmitter receiver distances. Figure 5.10 shows the comparison of bit error rate versus signal to noise ration plot for binary phase shift keying modulation and on-off keying modulation techniques. It clearly shows that BPSK gives better BER performance than orthogonal modulation techniques like OOK.

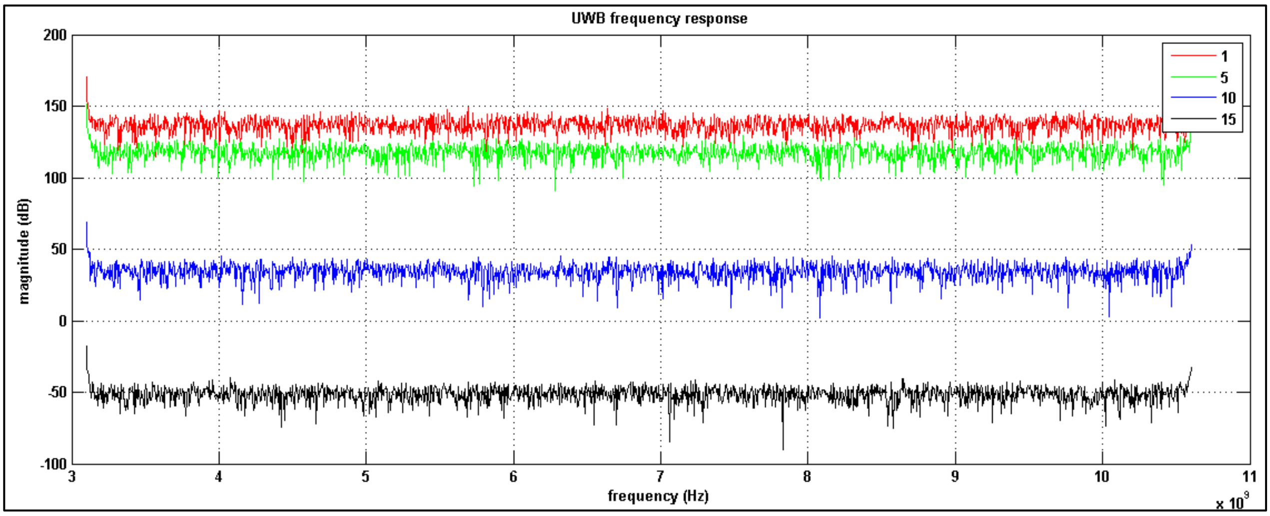


Figure 5.3: UWB Frequency Responses

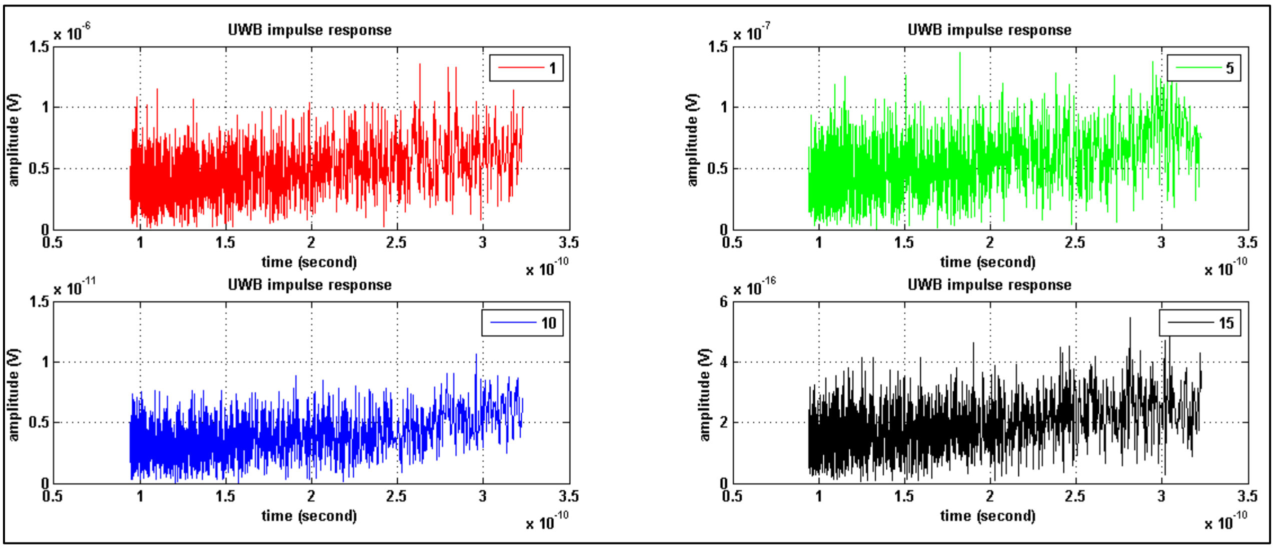


Figure 5.4: Corresponding Channel Impulse Response

Above figures are the frequency and impulse responses of the modelled channel inside tunnel. Channel frequency response is plotted for strength of received electric field versus frequncy, for 1m, 5m, 10m and 15m transmitter receiver distance. Different distances conisdered because receiver is moving inside tunnel as it is mounted over the train. So with increase in distance electric field strength start to dcrease from the level of 150 dB to the level of -50 dB. Multipath fading is the reason for this attentuation in signal strength.

Channel impulse response is plotted for amplitude of impulse versus time. Impulse response plot also shows that amlitude of impulses rdeuces from the order of 10^{-6} volt to the order of 10^{-16} volt with increasing distance.

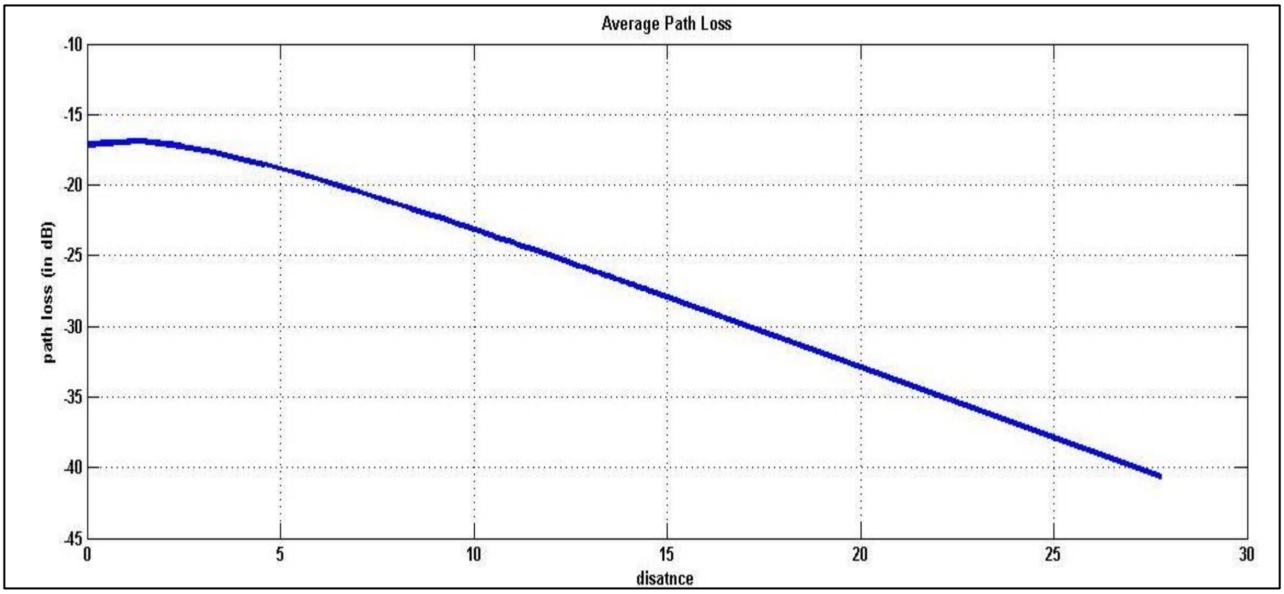


Figure 5.5: Average Path Loss

Above plot shows the distance dependent path loss averaged over UWB frequency band over the communication ranges of 1 to 600 m [8]. Plot shows that for the first 100 meter distance path loss value decreases by 16 dB than from next 100 meter onwards it decreases approximately by 5 dB.

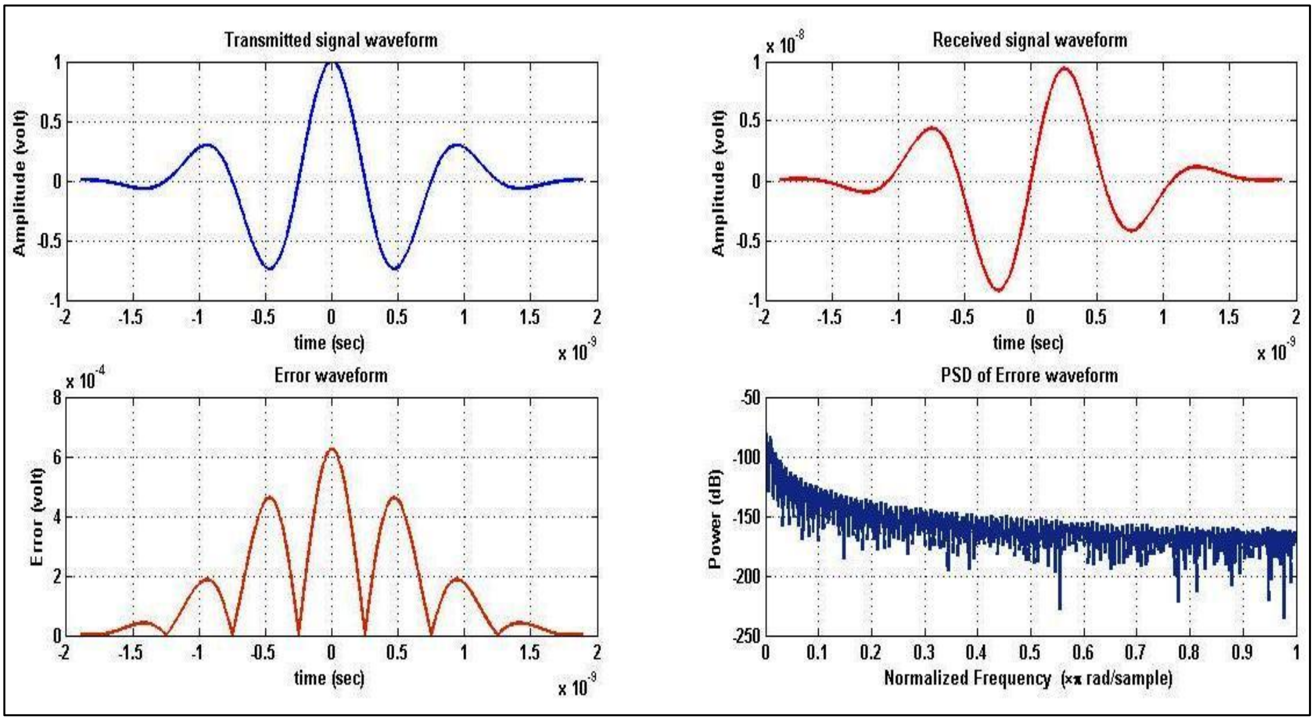


Figure 5.6: Gaussian impulse

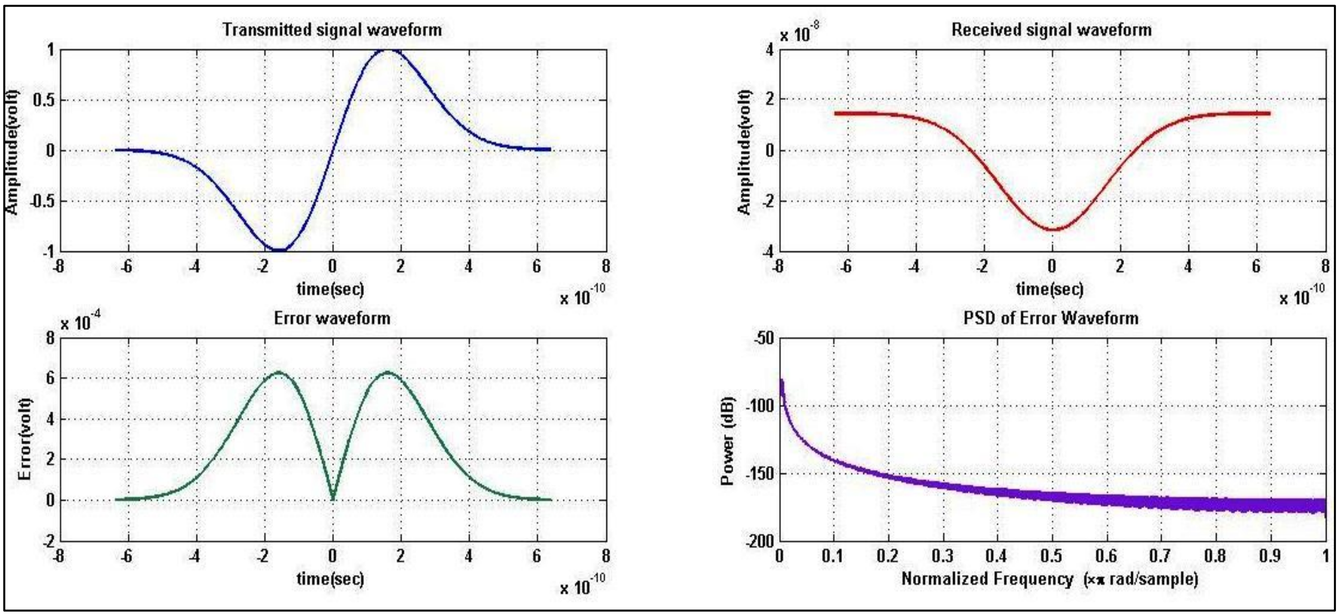


Figure 5.7: Gaussian Mono-pulse

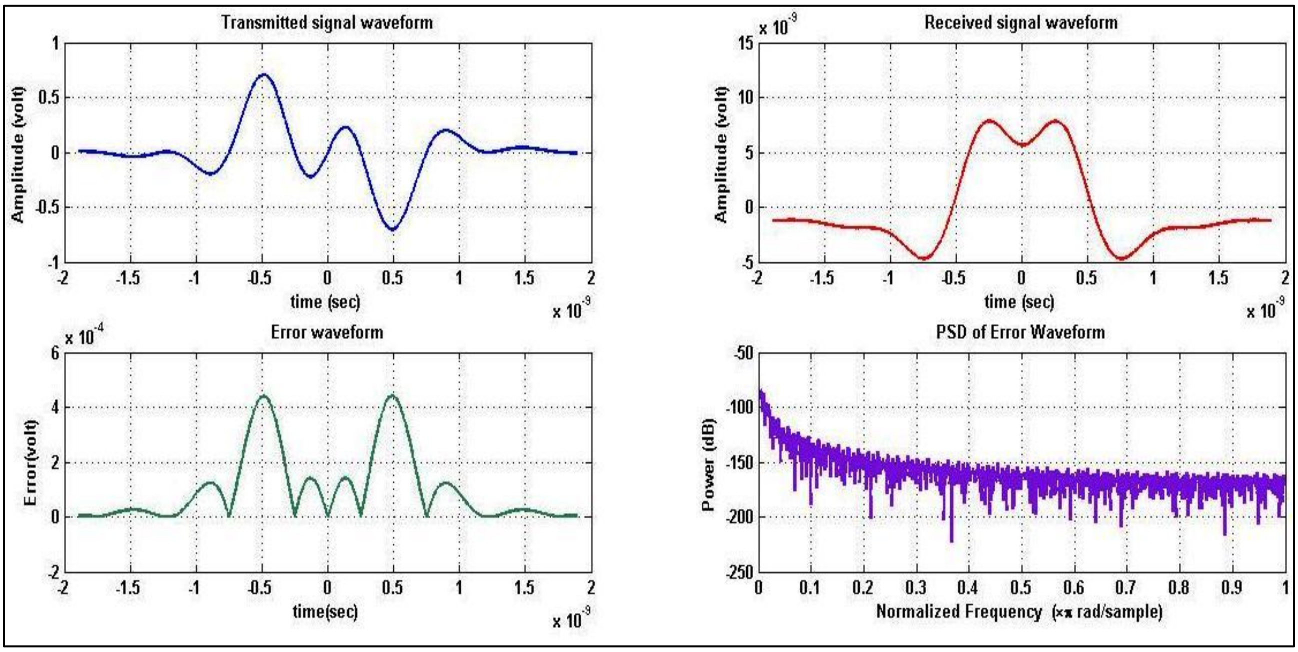


Figure 5.8: Truncated Sinusoidal Pulse

Figure 5.6 to 5.8 shows plots for transmitted and received pulses over the channel. It shows that modelled channel provide the phase shift and time shift to the propagated waveforms, this is a basic property of multipath channel (equation 5.1). Time shift and phase shift calculated for 1m, 5m, 25m and 55m distances with Gaussian pulse, Gaussian mono-pulse and truncated sinusoidal pulse. It is summarized in the table 5.2, from which we can observe that among all, up to the distance of 25 meter Gaussian impulse faced less delay in both phase and time in comparison with Gaussian mono-pulse signal, while truncated sinusoidal signal faces advancement in phase and time. Power spectral densities shows that power spreads in the range of -100 dB to -200 dB over the UWB frequency band. Variations in PSD for all type of wave shapes are almost same because all are based on Gaussian pulse.

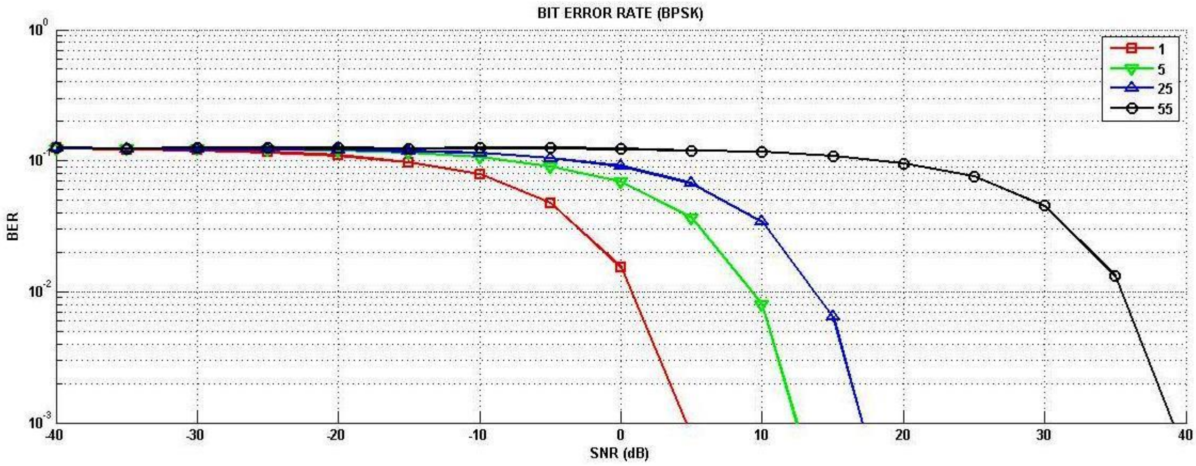


Figure 5.9: Bit error rate performance for UWB channel

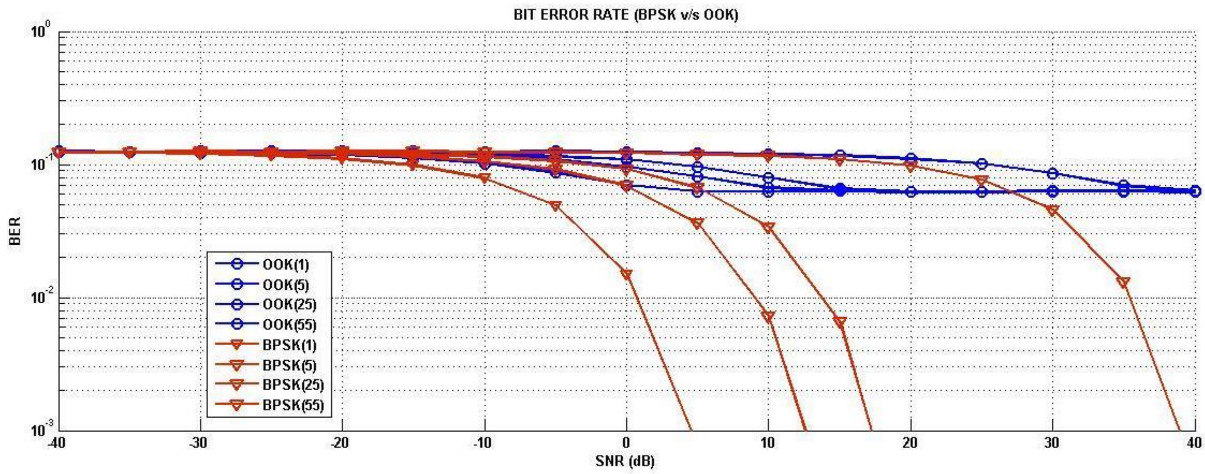


Figure 5.10: Comparision of BER for BPSK and OOK modulation

Figure 5.9 and figure 5.10 shows the plot for bit error versus signal to noise ratio up to the distance of 55 meter. Figure 5.9 shows the BER performance of modelled channel with binary phase shift keying modulation. It contains four plots for four different distances through which we can observe that with increasing distance BER performance degraded because of multipath fading and distance dependent path loss. To maintain the BER value of 10^{-3}, increase in SNR value with distance is shown below:

TABLE 5.3

DISTANCE V/S SNR (BER = 10^{-3})

Distance (m)	SNR (dB)
1	5
5	13
25	17
55	39

Figure 5.10 shows the BER comparison between BPSK and OOK modulation techniques. Bit error rate performance for BPSK is better than OOK, as BPSK is a bi phase modulation technique and distance between two bits are more than in OOK technique, so it is more immune to the interferences.

5.3 SUMMARY

This chapter presented the details about mathematical descriptions of the problem, simulations done on the basis of these mathematical description and simulation setups. Channel characteristics analysed by evaluating frequency response, impulse response and path loss. Effect of channel over three standard UWB pulse shapes observed. Bit error rate performance evaluated for BPSK and OOK modulation techniques.

Chapter 6

CONCLUSION & SCOPE OF FUTURE WORK

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6.1 CONCLUSION

A new promising technique is adopted by communication community is ultra-wideband technology which offers a solution for high bandwidth, high data rate, low cost, low power consumption, position location capability, resilience to multipath fading etc. These benefits of UWB motivate to apply it for railway transportation. So we can get faster and safer mode of transportation. To implement this new wireless technology we choose the most critical portion of railway network, as inside tunnel existing narrow band wireless communication system gets highly attenuated. To design an effective UWB communication system for railway tunnel, it is must to understand the UWB propagation characteristics in tunnel. Tunnel represented as an oversized waveguide and ray theory model of propagation used. Tunnel assumed as multipath fading channel with additive white Gaussian noise. So the effect of small scale fading and path loss evaluated up to the distance of 55 meter. Bit error rate performance evaluated to test the quality of reception.

Research work done to design UWB based radio wireless communication system for railway tunnel, is concluded under following points:

- UWB is immune to multipath fading and path loss over a short distance of about 15 meter. It is also well known that UWB has very high speed within this range of the order of 480 Mbps.
- Effect of fading over the channel response is that the strength of electric field and amplitude of impulses start decreasing with distance. It is because with increasing distance possibility of receiving multipath components in constructive way decreases.
- The bit error rate performances get degraded due to multipath fading effect which is evaluated for the extended distance of 55 meter.
- Comparison of BER for BPSK and OOK modulation techniques shows that BPSK is more immune to interference in comparison with OOK. It is because BPSK modulates the bits into two opposite phases (1 and -1) which results more separation between two consecutive modulated bits.

So UWB radio wireless communication has a very great potential to provide high speed data streaming over short range which makes possible to establish a fast and reliable communication system to control the train inside railway tunnel.

6.2 SCOPE OF FUTURE WORK

As a scope of future work, with this much high data rate of UWB systems, driver less subway transportation system can be established in which both voice and video data transmission will possible.

This research work is proposed for rectangular shaped railway tunnel only so the study can be extended for other railway tunnel geometries.

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REFERENCES

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